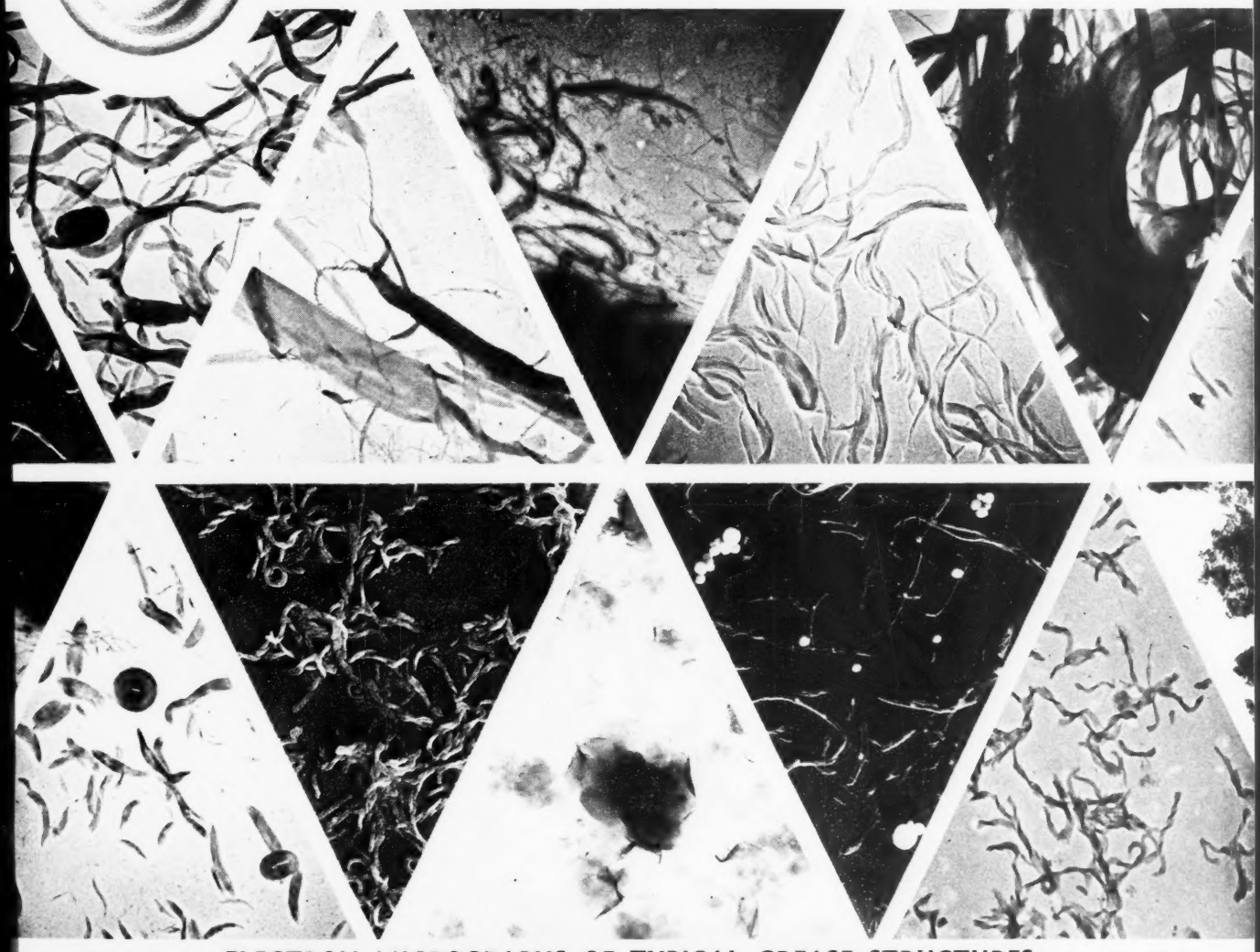
Practical Feature: LUBRICATING GREASES

JUNE, 1953
Vol. 9, No. 3

Lubrication ENGINEERING



ELECTRON MICROGRAPHS OF TYPICAL GREASE STRUCTURES

JOURNAL OF
THE AMERICAN SOCIETY OF LUBRICATION ENGINEERS

PRESS BUILDER USES Trabon SYSTEMS FOR POSITIVE LUBRICATION

Photo courtesy Clearing Machine Corp., Chicago

this has a BEARING on the subject

TRABON *automatic* lubrication on this Clearing forging press lubricates 36 bearing points while the press operates under full load. This completely trouble-free system has eliminated bearing burnouts and costly shutdowns.

A TRABON system on *your* equipment will do the same job efficiently, economically and positively.

Remember, it's impossible to under-lubricate or skip a bearing with a TRABON positive system . . . a single indicator at the pump tells the operator when every bearing is properly lubricated.

Fully hydraulic . . . economical . . . for oil or grease . . . safe . . . completely sealed.

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154 ideas on ways to use...

154 varied applications of molybdenum sulfide in the shop and in the field are described in a new booklet now available. This solid-film lubricant has demonstrated unique anti-friction properties under conditions of extreme pressure, high velocity, elevated temperature, or chemical attack.

The 40-page booklet contains the records of solved lubrication problems — some might solve your own.

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MOLY

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Lubrication ENGINEERING

JUNE, 1953, Vol. 9, No. 3

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Manzel's

MECHANICAL MAINTENANCE MEN

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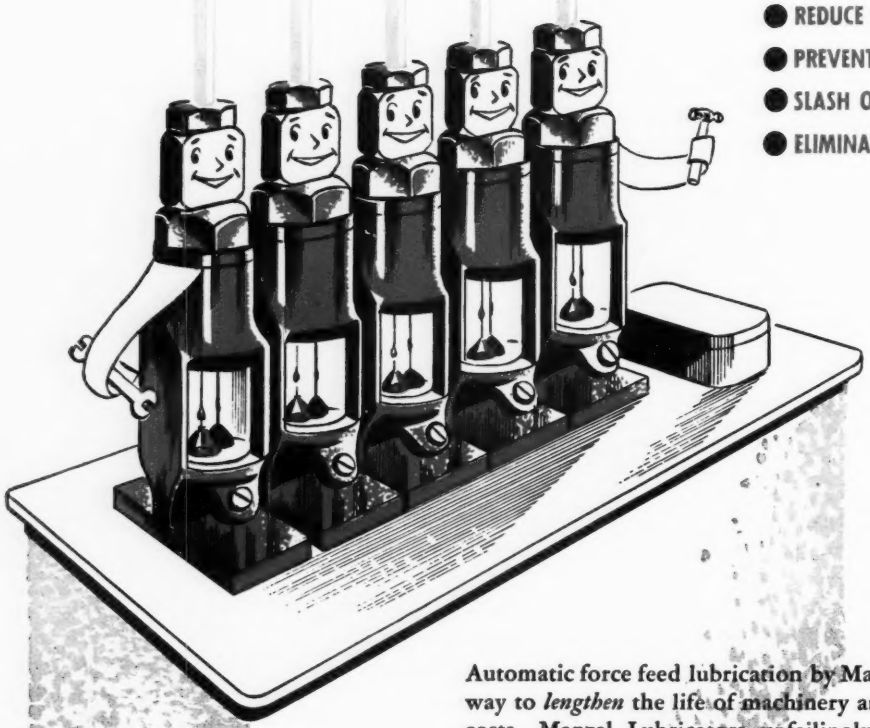
- PREVENT BREAKDOWNS
- SLASH OIL CONSUMPTION
- ELIMINATE DOWNTIME



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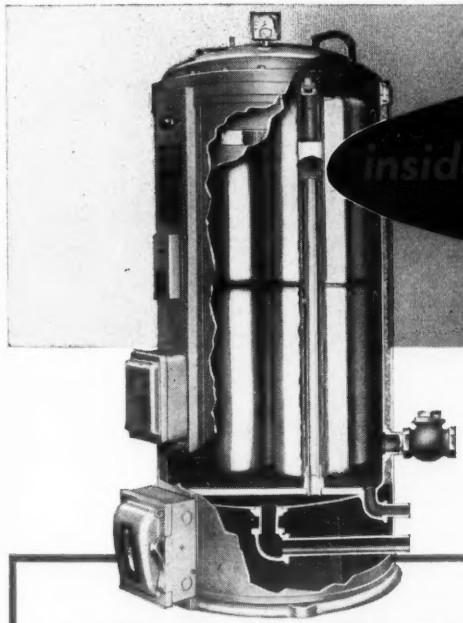

inside tip...

only HONAN-CRANE ... DIESEL OIL PURIFIERS give you so many vital ENGINEERING FEATURES

The Honan-Crane "Multi-Cartridge" Purifier is engineered, inside and out, to provide the high-flow, *thorough* oil purification essential for diesels. Removes *all types* of harmful contamination . . . substantially reduces engine wear and maintenance costs . . . quickly pays for itself in oil savings alone!

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2. Clean oil is drawn from top of purifier. Maximum efficiency of each cartridge is utilized.
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4. Electric heater bands maintain correct oil temperature. Steam, hot water heating available.
5. Oil-and-gas-tight seals and gaskets prevent seepage. Dirty oil cannot contaminate clean oil.
6. Double-decked cartridges save floor space, permit clean design, greater operating efficiency.
7. Positive locks and pressure springs keep cartridges securely in place, prevent by-passing.
8. Purifier is fully equipped with automatic controls and safety features. Requires no attention.

INTERCHANGEABLE CARTRIDGES FOR HONAN-CRANE PURIFIER

TYPE "MC"—Cotton bag packed with Cranite (fuller's earth). Removes solids and products of oxidation . . . acids, gums, etc. Provides refinery-type purification.

TYPE "MF"—Perforated metal basket packed with Palconia (cellulose fiber). Recommended for additive oils for complete removal of dirt, scale and other solids.

TYPE "S"—Contains Palconia (cellulose fiber). Performs same as Type "MF." Fiber center-tube permits complete disposal of spent cartridge by burning.

TYPE "E"—Similar to Type "S" except that filtering material is cotton waste and excelsior. Type "E" is recommended when water is encountered in the oil.

WRITE US ABOUT YOUR OIL PURIFICATION PROBLEM

Honan-Crane Fuel and Lube Oil Purifiers are available for any size or make of Diesel Engine. For detailed information, write Honan-Crane giving make, model and H.P. of your diesel. Describe any unusual aspects of your oil purification problem.

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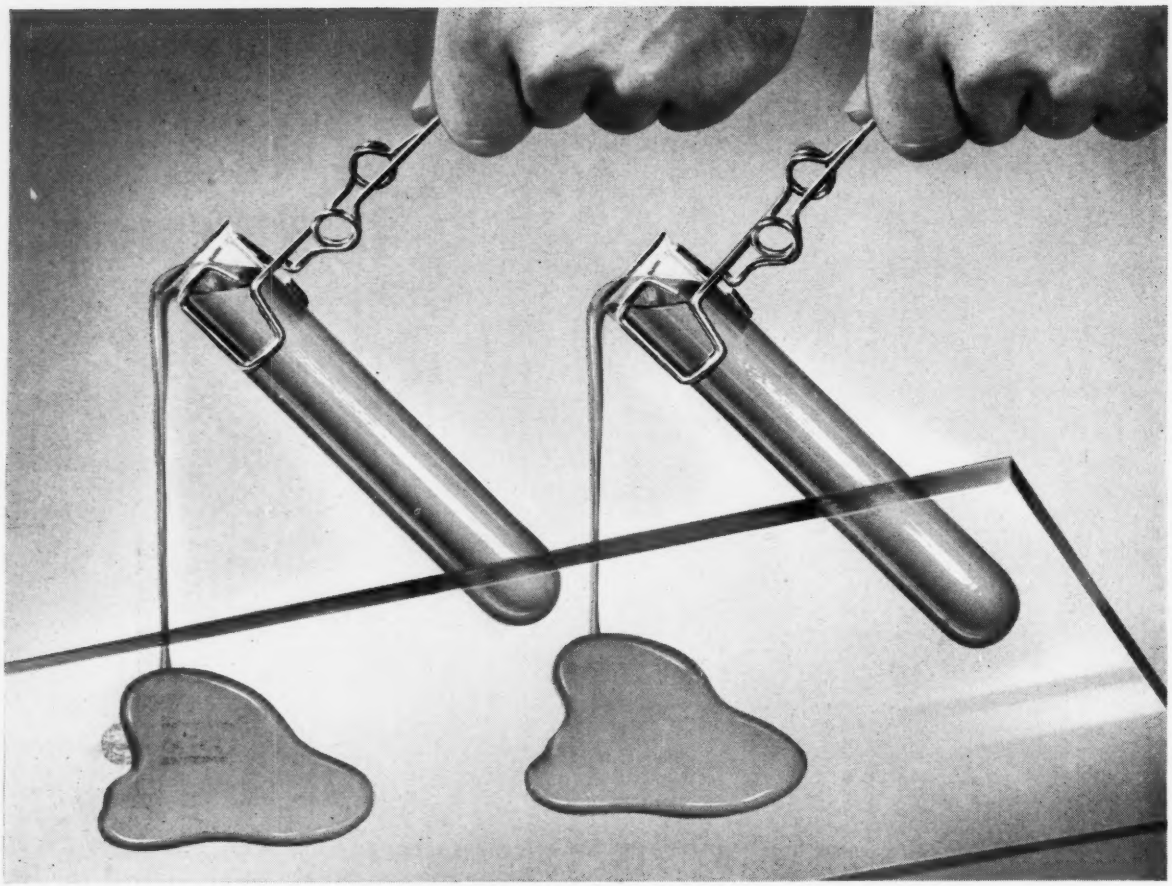

Which lubricant has increased tin plate production 15%?

Both lubricants look, feel and act alike — yet tin plate mills using the one on the right—Palmoshield—have increased production as much as 15%.

A leading steel company adopted Palmoshield for cold rolling operations and recently over a run of 20 consecutive shifts, production was stepped up 15% over the average output with imported oil. This increase was made with no additional investment, no increase in labor force, no extra machines and no changes in mill operation. Yet 115 tons of steel were rolled for every 100 before.

Nearly two-thirds of the major tin plate mills in this country and Canada are now using Palmoshield for regular mill operations or on-the-job-test runs.

Advantages of Palmoshield

Palmoshield is produced in the heart of the steel industry. Users are not dependent on overseas shipment from foreign controlled sources.

Palmoshield is made from domestic materials freely available in sufficient quantities to supply all American steel production.

Palmoshield need not be stockpiled by the user, yet it does not deteriorate in storage.

Palmoshield is tailor-made to your needs. Free fatty acid content can be controlled to within ½%.

Technical assistance for your own operations.

On request an Ironsides representative will give you facts on Palmoshield to help you set up a test program in your mill.

Palmoshield is available for same-day shipment in 55-gallon drums and tank car lots. For full information write The Ironsides Company, 270 West Mound Street, Columbus, Ohio.

SPECIAL LUBRICANTS and PRESERVATIVES

IRONSIDES SHIELD PRODUCTS PALMOSHIELD

telling the story of 'dag' dispersions

This *Dry Film* Lubricates Successfully At 500°F. and Up

'dag' colloidal graphite—easily applied to anything by spraying, painting, or dip-coating—produces a durable *dry lubricating film* that won't gum up or break down at the high temperatures which ordinarily ruin common lubricants. It is not at all bothered by heat up to 750°F., and for most practical purposes it is useful at much higher temperatures. **'dag'** dispersions come in a variety of liquid carriers: water, oils, volatile hydrocarbons.

'dag' colloidal graphite is not ordinary powdered graphite. It is high-purity, electric-furnace graphite, specially treated by Acheson Colloids to produce particles many, many times finer than those of powdered graphite.

Properties: Dry solid . . . softer than talc . . . unaffected by heat up to 750°F., and up to 3000°F. in inert atmospheres . . . dispersible in many fluids, co-dispersible with many solids . . . chemically inert, impervious to degreasing agents . . . anti-corrosive . . . heat-conductive, electrically conductive . . . gas adsorbent . . . has low coefficient of expansion.

Uses: In forging, in foundry-casting and die-casting, in piercing, deep drawing, stretch-forming, extruding, spinning, wire drawing, ingot-mold stripping, press-fitting, cutting . . . for assembly and run-in . . . for permanent lubrication by impregnation or coating . . . in almost any process where friction-fighting is demanded at high temperatures.

For more information on this unique lubricant ask for Bulletin No. 424-12F and No. 435-12F.

Dispersions of molybdenum disulfide are available in various carriers. We are also equipped to do custom dispersing of solids in a wide variety of vehicles.

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Over 300 Tycol industrial lubricants are at your disposal . . . engineered to fit the job!

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This lubricator becomes an integral part of a machine tool in which there are 48 vital bearings that require dependable lubrication. The Madison-Kipp mechanism is so compact that the reservoir measurements are only 4" wide, 19¾" long by 5¾ high."

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kipp

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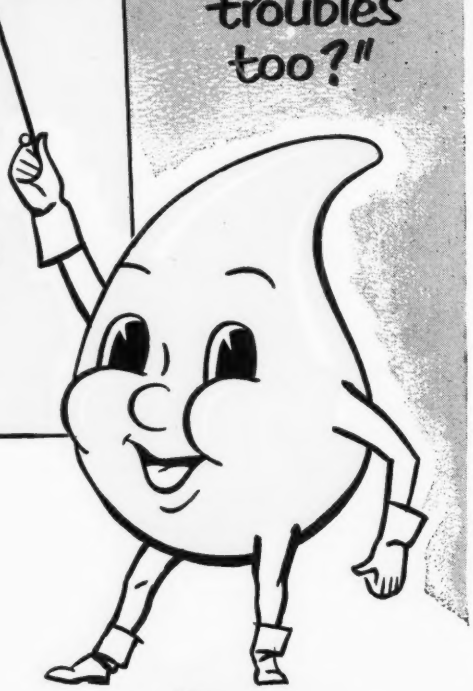
Evils of low temperature—intermittent engine operation

- Exhaust smoking
- Oil screen plugging
- Crankcase and valve chamber sludge
- Sticking valves and plugged oil rings
- Rapid wear of critical moving parts



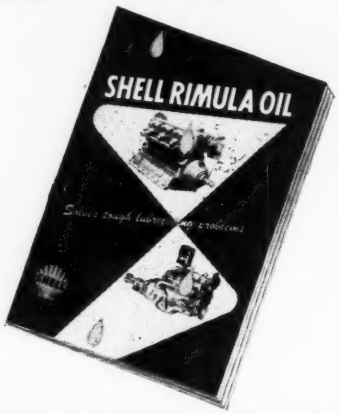
"Read about the oil that laughs at 'em!"

THE engines that do our modern moving and shifting chores around the plant take more of a beating than meets the eye. Lift trucks are a good example. They idle much of the time . . . start and stop and work and loaf, week in and week out. That's the service that brings on the complaints listed.

Shell has met this problem with a special lubricating oil that literally clears these evils out of the picture. Shell Rimula Oil takes care of any of them . . . or any combination of them.

This is the product with a service record adding up to hundreds of thousands of miles . . . in delivery truck operation; in diesel and gasoline engines, both automotive and stationary; on construction projects; in farm machinery; in numerous plants.

Shell Rimula Oil is setting new standards of performance in low temperature—intermittent engine operation. Try it and see!

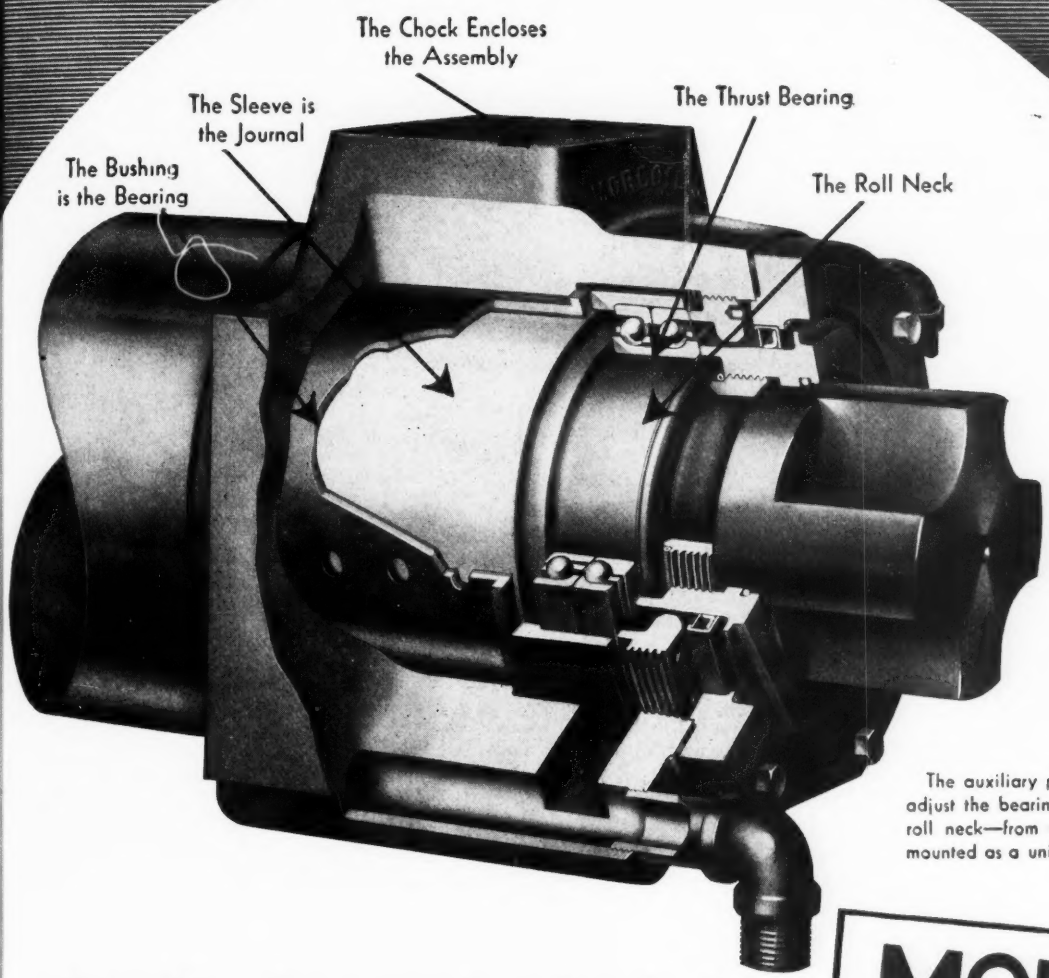


For further information on the cost-cutting advantages of Shell Rimula Oil, write Shell Oil Company, 50 West 50th St., New York 20, N. Y. —or, 100 Bush St., San Francisco 6, California.

SHELL RIMULA OIL

SHELL

MORGOIL
ROLL NECK BEARINGS



The auxiliary parts serve to seal and adjust the bearing and secure it to the roll neck—from which it is easily dismounted as a unit.

How Simple can a bearing be?

One reason for the high efficiency of Morgoils . . . and their low operating and maintenance costs . . . is their extreme simplicity of design. Each part is there for a purpose . . . and each contributes to make Morgoils the most widely accepted roll neck bearings.

MB 13

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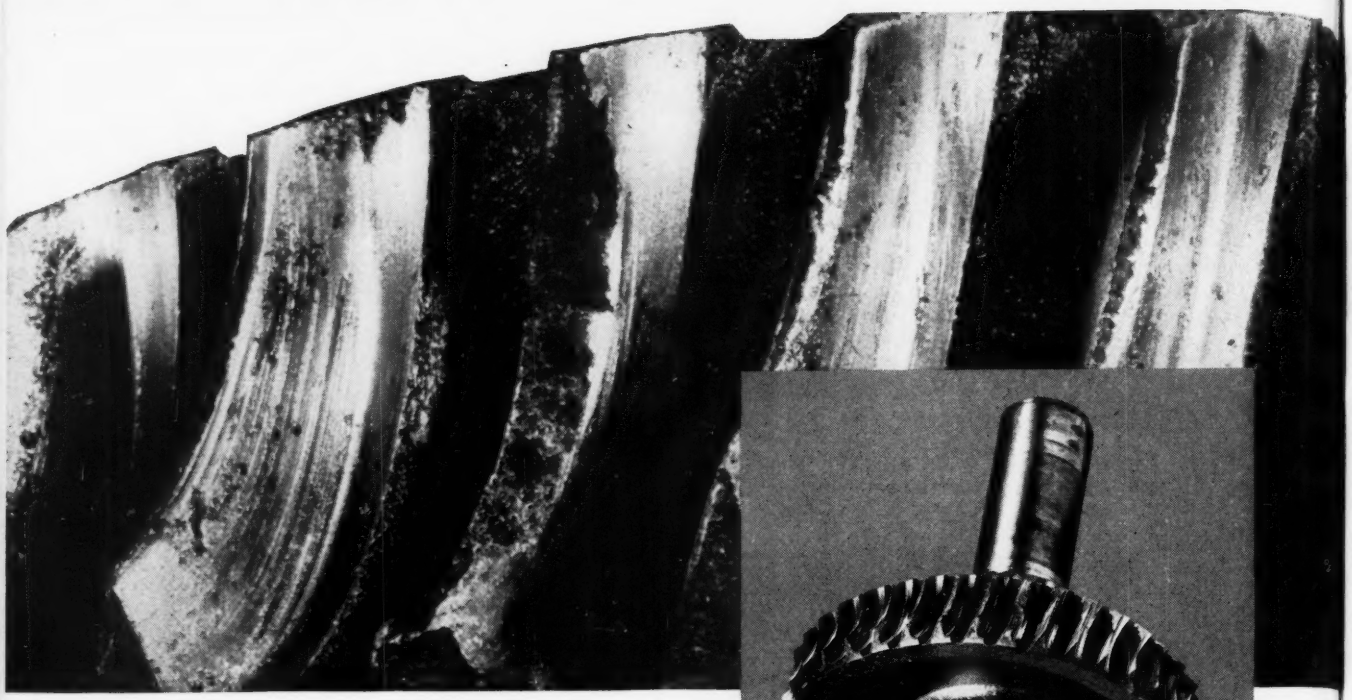


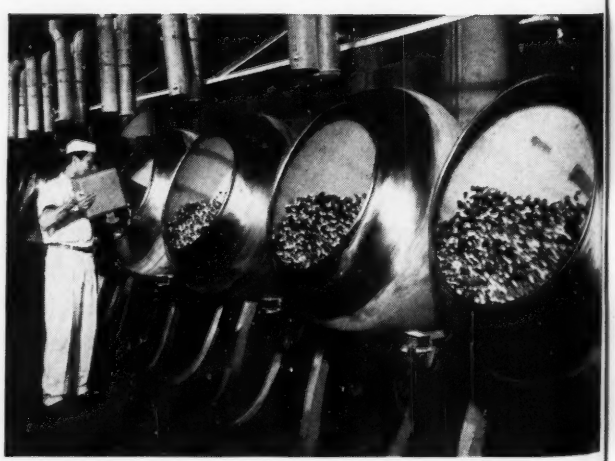
Unretouched photographs of worm gear ruined by former lubricant. The teeth are badly worn and galled, and in some cases they have broken off. The sugar and starch laden atmosphere, high temperature, extreme overload, and slow speed demand a lot of a lubricant.

SUNEP ELIMINATES FAILURE OF SLOW-SPEED WORM GEARS

To help satisfy America's sweet tooth, Leaf Brands, Inc. resorted to a 70% overload on its revolving candy pans. This weight, plus slow speed, sugar and starch-laden atmosphere, and surrounding high temperatures, resulted in an average of 450 worm gear unit failures in one year. The lubricant could not take it.

After a test of a number of extreme pressure lubricants Sunep was selected. Because of damage caused by the former product, some units broke down during the first months following the change-over. But in the last 5½ months there hasn't been a single failure. Far less Sunep has been required, and records show an overall saving of over $20,000 in the year it has been in use.

Send for our new booklet "Sunep"—it will not obligate you. SUN OIL COMPANY, Philadelphia 3, Pa., Dept. LE-6



These revolving candy pans operate at 30 rpm. Sunep keeps them turning in spite of 70 percent overload.

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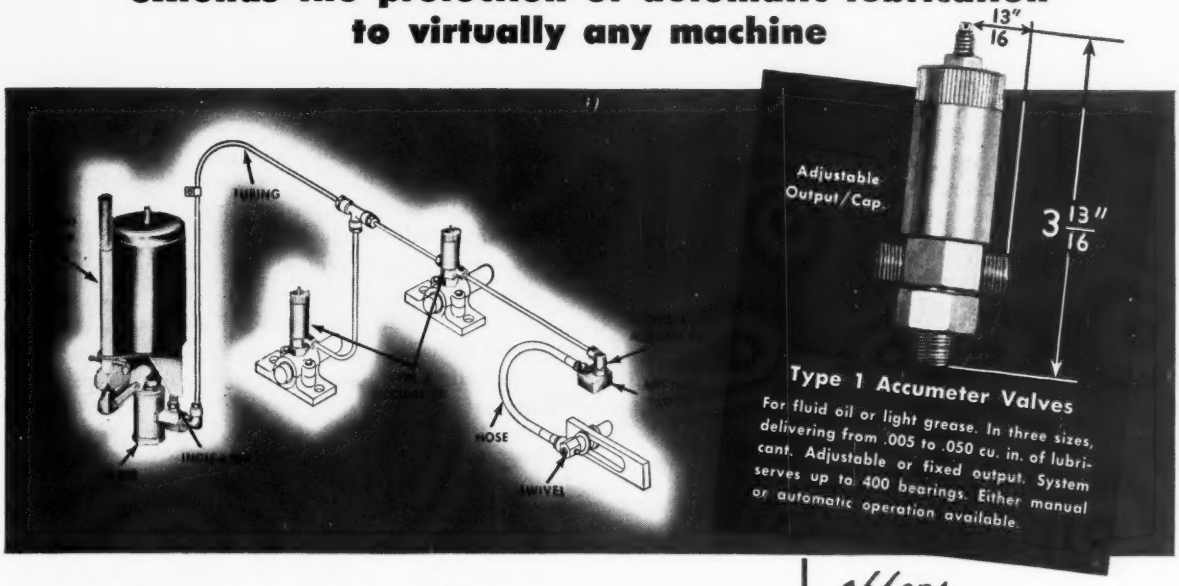
Designed...to eliminate hit-or-miss machine lubrication

ALEMITE Accumeter® CENTRALIZED LUBRICATION

extends the protection of automatic lubrication to virtually any machine



Type 1 Accumeter Valves

For fluid oil or light grease. In three sizes, delivering from .005 to .050 cu. in. of lubricant. Adjustable or fixed output. System serves up to 400 bearings. Either manual or automatic operation available.

Centralized lubrication with Alemite Type I Accumeter can make your machines produce more, last longer, and cost less to run—*impressive savings at low cost!* This simple, single-line system is completely versatile—easy to design, easy to build into any machine because valves fit directly on bearings, replacing grease fittings, oil cups or reservoirs.

In seconds, in a fraction of the time required for hand lubrication, Alemite Accumeter Lubrication System delivers the exact, measured amount of clean oil or grease *from one central point* to all bearings of a machine. The machine keeps operating—no production time lost—no bearings are missed. No wonder 95% of big plants buying machine tools specify *centralized lubrication!*

Type 1 Accumeter Systems serve single machines or groups of machines with semi-automatic or fully automatic lubrication. It is just one of three types of Accumeter Systems made by Alemite to meet your exacting requirements.

offers...

ALL THESE ADVANTAGES!

- **Eliminates shutdown time for lubrication. Adds productive time to machine output.**
- **Seals completely against dirt, grit, water all the way from "Barrel-to-Bearing."**
- **Prevents bearing troubles due to neglect or use of wrong lubricant.**
- **Services *all* bearings—including those inaccessible or dangerous—in one operation.**
- **Avoids work spoilage and bearing repairs due to over-lubrication.**

FACTORY-TESTED . . . FIELD-PROVED

Proved in the field. Exhaustive tests showed *no variation* in the amount of lubricant discharged . . . even after 73,312 lubrication cycles, *equal to 122 years of twice-a-day service.*

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DOW CORNING

Silicone Notes

ON LUBRICATION

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FILE	SILICONE LUBRICANTS

For more information please ask for Data sheet 3-201 on Dow Corning 200 Fluid; Data sheet 6-200 on Dow Corning 33 Grease.

DOW CORNING CORPORATION
Dept. BW-6, Midland, Mich.

DOW CORNING 200 FLUID

Materials with a combination of properties as unusual as those of the Dow Corning 200 Fluids invite experimentation. Quite often this leads to unusual applications. Some of them may be highly specialized, but all of them result in better performance or lower production costs. You will find a few typical applications reported in this column.

In planishing aluminum alloy sheet, tests in an aircraft plant indicate that a film of Dow Corning 200 Fluid minimizes scuff marks. Residual silicone is removed by solvent wash or degreasing.

On motion picture film, a 2% concentration of Dow Corning 200 Fluid in a solvent shows promise as a wipe-on lubricant. Film life is increased and the projected picture is not distorted in any way.

Crimper bars in a book binding plant don't scratch plastic bindings when lubricated with Dow Corning 200. The operator simply dips her finger into the silicone fluid and lightly touches two spots on every 200th cover. Enough silicone carries out on the bars to lubricate the next 199 covers.

In cutting magnesium, a manufacturer increases the life of his circular saw blades by brush coating them with Dow Corning 200 Fluid. He reports that one application per shift makes blades last 2 to 4 times as long in cutting magnesium; as much as 64 times as long as untreated blades in cutting steel-cored magnesium anodes.

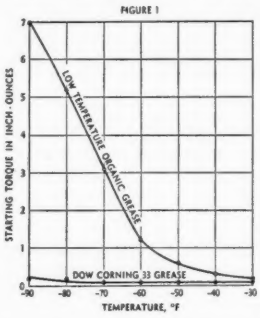
Phonograph records sprayed with a 10% solution of 200 Fluid are reported by an independent observer to become less dusty and to play with greater fidelity and less surface noise.

DOW CORNING 33 GREASE

Dow Corning 33 Grease, has better low temperature characteristics than organic greases that meet MIL-G-3278 specifications. It is also more stable than special high temperature petroleum greases at temperatures in the range of 300-400°F. Total loss due to bleed and evaporation at 300°F is comparable to that of good high temperature petroleum greases and less than half the loss measured for a typical low temperature synthetic grease that meets MIL-G-3278 specifications. At 390°F, total loss for Dow Corning 33 Grease is only 5.8% compared with 20 to 40% for the high temperature petroleum greases and 97% for the low temperature greases.

Low temperature performance is even more spectacular as indicated by a measurement of torque in bearings lubricated with Dow Corning 33 Grease and with a low temperature organic grease at temperatures in the range of —30 to —90°F. These data are plotted in Figure 1.

FIGURE 1



That's why Dow Corning 33 Grease is used as a lubricant for conveyor systems traveling through deep-freeze chambers; for bomb ejectors that must be operable at temperatures in the range of —70°F; and for camera shutters, rotating beacon lights, small synchronous motors and instruments exposed to both arctic and tropical temperatures and to outdoor weathering.

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DOW CORNING SILICONES

Lube Lines

Incoming ASLE President W. E. Campbell (right), Bell Telephone Laboratories, is presented with the gavel by Retiring President M. E. Merchant, The Cincinnati Milling Machine Co., at the ASLE Annual Banquet, Hotel Statler, Boston, April 14, 1953.

PRESIDENT'S MESSAGE: Our Society starts its 9th year, after completing an outstandingly successful year, with every prospect of continuing the vigorous growth which has characterized it from the beginning.

During 1952, our National Office has been reorganized by our friendly and energetic Administrative Secretary, W. P. Youngclaus, Jr., to give even more efficient service than before; our magazine has been expanded and improved under the leadership of Dr. S. K. Talley; a Speakers Bureau has been organized by our Research and Special Projects Chairman, E. M. Glass; the experimental First National Symposium held in September 1952 proved to be very popular. Its proceedings will be published this year.

As emphasized by our Retiring President, M. E. Merchant, in his message last year, service is the primary objective of our Society—service to our membership, to industry, and to the public. This objective will be steadfastly maintained by the continuance of former services and by expanding and adding to them wherever possible. Among services which are continuing are the sponsorship of education programs in universities and cities where our sections flourish. This year we will sponsor a summer lubrication course at Northwestern University, June 15-24, and the popular course at Massachusetts Institute of Technology will be continued with our assistance for the third successive summer, (June 16-26). Work on the educational monograph series will continue. The newly formed Speakers Bureau will function as a subcommittee of our program committee. This project can be expected to have a great vitalizing effect on our Sections' activities, by providing them with experienced speakers of high caliber for their meetings. The many eminent specialists in our Technical Committee will continue to serve by providing answers to questions on all branches of lubrication addressed to them. They will also continue to help obtain technical papers for our annual meeting. Programming plans for this meeting, which will be held in Cincinnati, April 5-7, 1954, are already under way.

As a means of expanding service to our members, a special committee of the General Technical Committee has been set up under the Chairmanship of F. J. Schmitt to conduct a questionnaire to our membership. This will be designed to determine whether our present services are adequate and how they can be improved. The questionnaire is being planned and will be interpreted using techniques applied by a leading expert in consumer preference opinion surveys. It is hoped that every member will cooperate to serve his own interest as well as those of the Society by filling out and returning the questionnaire promptly when it arrives.

The science of lubrication is devoted to the important task of reducing wear and friction in industrial machinery. As operations in our economy become more highly automatized, a trend which is clearly evident, the applications of the science become more ramified. Basic research on the significant properties of lubricants, and on methods for their most effective application, on bearing design, and on bearing materials, is essential to the development of the science. A.S.L.E. has a two-fold function; on the one hand, it must organize and systematize the best current lubrication practice; on the other, keeping in mind that the research of today is the practice of tomorrow, it must foster the basic research necessary to meet the lubrication demands of our expanding industry. In either event, it must present the results to its membership and to industry in clear, understandable and readily applicable form.

Our youthful Society has already made a notable contribution to this job. Your chosen representatives pledge themselves during the coming year to continuing the work which has been so well started. W. E. Campbell

Wilfred E. Campbell, a Member of the Technical Staff of the Bell Telephone Laboratories in charge of lubrication studies and of analytical methods development, has been active in the science and practice of Lubrication Engineering since 1928 when he was asked to initiate basic studies in lubrication for the Bell Laboratories.

He was born in Durban, South Africa, June 28, 1903, and obtained his Doctor of Science degree in physical chemistry from the University of the Witwatersrand.

Dr. Campbell's research interests have been centered largely around thin film studies, both in the field of lubrication and of corrosion. He has published numerous papers giving the results of his studies in these fields. In recent years, he has also been engaged in research on analytical methods associated with communications problems.

He is an active member of ASLE, ASME, ACS, and ASTM. He has been a member of the Special Research Committee on Lubrication of ASME since 1932; he is a member of the Sub-Committee on Lubrication & Wear of the Committee on Power Plants for Aircraft of NACA, and is a member of the CLR Airframe Lubricants Group of the CRC. In A.S.L.E. he has served as a Director, as Vice-President at Large, as Chairman of the New York Section, and as a member of the Education and General Technical Committees.

Dr. Campbell married the former Mary E. Maxted of Springfield Center, New York, on September 28, 1928. They have three sons and live in Summit, New Jersey.

NINTH NATIONAL CONFERENCE ON INDUSTRIAL HYDRAULICS: The Illinois Institute of Technology will be host to the 9th National Conference on Industrial Hydraulics, October 8-9,

1953, at the Hotel Sheraton, Chicago. Conference director will be O. E. Teichmann, assistant chairman of the Heat-Power department at Armour Research Foundation of I.I.T.; Carl E. Schmitz, vice-president of the Crane Packing Co., will be associate director. Societies helping to stage the Conference include: the Illinois Section of the American Society of Civil Engineers, Chicago Section of the American Society of Mechanical Engineers, Chicago Section of the Society of Automotive Engineers, Western Society of Engineers, American Society of Lubrication Engineers, Chicago Section of the American Institute of Chemical Engineers, Chicago Section of the Institute of Aeronautical Science, American Society of Agricultural Engineers, Chicago Chapter of the Illinois Society of Professional Engineers, and the Chicago Chapter of the American Society of Tool Engineers.

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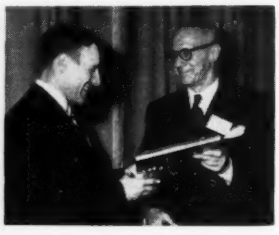
ANNUAL MEETING HI-LITES, 8th ASLE Annual Meeting & Exhibit, Hotel Statler, Boston, Massachusetts, April 13-14-15, 1953:

(Left) The Alfred E. Hunt Memorial Medal, sponsored by the Aluminum Company of America, was awarded to D. G. Faust (right), C. A. Norgren Co., for the best paper on the subject of lubrication in 1952.

(Right) The ASLE National Award, signifying life membership in the Society for an individual making outstanding contributions to the furtherance of the science and practice of lubrication, was awarded to J. J. Simon, Sinclair Refining Company. Mr. C. M. Larson (right) accepted the award in Mr. Larson's absence.



(Left) The Walter D. Hodson Award, awarded annually for the best paper on lubrication or an allied subject by a member 30 years of age or less, was presented to A. C. West (right), California Research Corporation.

(Right) Retiring President M. E. Merchant (left) is presented a testimonial plaque of appreciation by the Chairman of the Presidential Council C. E. Schmitz (right), Crane Packing Company.

(Left) Lt. Comdr. H. J. White (USN Retired), as guest speaker for the ASLE Annual Banquet, presented an address entitled "Space Travel and National Security."

(Right) A partial view of the exhibits at the ASLE 8th Annual Meeting & Exhibit, Hotel Statler, Boston, April 13-14-15, 1953.

ASTM CHANGES FOUR VISCOSITY STANDARDS: As a result of a more accurate determination of the absolute viscosity of water by the Bureau of Standards (J. F. Swindells, J. R. Coe, Jr. & T. B. Godfrey: Absolute Viscosity of Water at 20 C. J. Research of the N.B.S., Vol. 48, No. 1, Jan. 1952, research paper 2279), Committee D-2 of ASTM are revising four viscosity standards as of July 1, 1953. The changed standards are:

D-445, Method of Test for Kinematic Viscosity.

D-446, Conversion of Kinematic Viscosity to Saybolt Universal Viscosity.

D-666, Conversion of Kinematic Viscosity to Saybolt Furol Viscosity.

D-567, Method of Calculating Viscosity Index.

The new value for the viscosity of water at 68 F. is 1.0038 centistokes compared with the old value of 1.0070 centistokes. All measured kinematic viscosities are correspondingly reduced 0.318% after July 1, 1953. Kinematic viscometers must be restandardized or recalibrated. Corrected conversion tables and V. I. index tables can be obtained from the American Society for Testing Materials, 1916 Race St., Philadelphia, Pa. Standard viscosity oils, distributed by the National Bureau of Standards and the American Petroleum Institute, will be revised to conform to the new standards after July 1, 1953. Viscosities on samples distributed earlier should be reduced by 0.318%. Saybolt Universal and Furol viscosities will not be changed, and consequently there will be no change in viscosity index. New tables must be used for calculating V.I. from kinematic viscosity. **(Continued on page 175)**

9th
A S L E
Annual Meeting & Exhibit
April 5-6-7, 1954
Cincinnati, Ohio

LUBRICATING GREASES *

by J. L. Finkelmann
The Warren Refining & Chemical Co.
750 Prospect Ave.
Cleveland 15, Ohio

Mr. Finkelmann received his BS degree in Chemical Engineering in 1933 and his MS degree in Chemical Engineering in 1935 from the Case Institute of Technology. After employment with the Lubrizol Corp. as research chemist doing basic research and development on additives for lubricating oils, gear lubricants and greases, he joined The Warren Refining & Chemical Co. as Chief Chemist in 1939. In 1943 he was appointed to the position of Vice-President and Director of Research & Production of the company.

Even though over a billion pounds was consumed in the United States last year, lubricating grease has generally been considered the "necessary evil" in the field of lubrication. How many times has the maintenance man or the lubrication engineer been heard to remark that he would never use grease, if it were possible to use oil? This same trend of thought has also been all too prevalent among designers of machine tools and other mechanical equipment. In designing equipment, it has been general practice to consider only the use of lubricating oil without giving the slightest consideration to the fact that grease might do the job better.

The mistaken belief that grease is merely a means of applying oil, has probably been caused by the lack of sufficient facts to form an accurate picture of the lubricating characteristics of a grease. Grease research in recent years has conclusively proved that greases do have certain unique characteristics that can be of great value in various lubricating applications. They are definitely more than "thickened oils."

Because of their semi-solid physical form, greases are obviously not suitable where complete fluidity is required. Yet, in other applications where fluidity would be a detriment, they render excellent service. Greases have directional fluidity. They flow only when a force is applied in excess of the yield strength of the grease structure. Because of this, they are able to lubricate properly many types of bearings, and to seal these bearings against external contaminants. The thickeners used in grease manufacture are usually polar in nature, and because of the attraction of these polar molecules for bearing metal surfaces, a thin film of lubricant is formed which stays on bearing surfaces far better than a non-thickened petroleum oil[1].

*Presented at the Conference on Lubricants and Their Manufacture, Case Inst. of Tech., Cleveland, April 5, 1952.

The above lubricant qualities are highly desirable in lubricating modern equipment and are characteristic of greases and not of oils. Greases, therefore, are a class of lubricants in themselves and have separate and distinct properties not found in other types of lubricants. They should no more be considered as mere substitutes for oils than should diesel engines be considered as substitutes for gasoline motors. Each type of lubricant as well as each type of engine is designed for a specific job.

Many lubricant manufacturers loosely define any lubricant sold by the pound as a grease. The definition taken from a 1950 edition of Funk & Wagnall's New College Standard Dictionary is even less helpful.

The American Society for Testing Materials definition says: "A grease is a combination of a petroleum product, and a soap or mixture of soaps, suitable for certain lubrication applications."

Although this was a satisfactory definition ten years ago, there are now many greases on the market containing silicones, diesters or polyglycols instead of petroleum oils, and silica gels, carbon black, or bentones[2] instead of soaps. (A benetone type thickening agent can be defined as the reaction product of a clay (Montmorillonite) and a long-chain amine.) The need for a new, up-to-date definition was suggested at the Annual Meeting of the National Lubricating Grease Institute in November 1949 to cover recent developments and ASTM now has it under consideration.

For the purposes of this paper, we will define lubricating grease as: "A liquid lubricant gelled by a dispersed solid. The finished product may or may not contain additives such as coupling agents, film strength improvers, oxidation inhibitors or mineral powders."

In an earlier article, in the series on the Fundamentals of Lubrication, G. W. Miller[3] covered lubricating grease from the standpoint of selection very completely. This paper will, therefore, review greases only from the standpoint of their composition, manufacture and properties.

OILS USED IN GREASE MANUFACTURE: Although it might appear to the layman that the selection of the oil to be used in grease manufacture is of minor importance, careful consideration

must be given to its choice, if the best possible product is to be developed for a specific lubrication job. In addition to the wide choice of mineral oils, many synthetic oils have been made available to the grease manufacturer within the past few years. This group included the silicones, diesters and polyglycols.

Only very general rules can be given for selecting the oil to be used in the manufacture of lubricating grease, and the final choice should be determined by the service for which the grease is intended. In a very general way, high viscosity oils should be used in greases for bearings under heavy loads and low speeds; low viscosity oils in greases for light loads and high speeds. For relatively infrequently lubricated bearings expected to remain in service for over long periods of time, highly refined oils of good oxidation characteristics should be chosen. Low cost, less-highly refined oils can be used in non-critical applications where leakage is high and the lubricant is to be replenished frequently. If the grease is to be used on low temperature applications, the oil must be chosen with the greatest emphasis on viscosity at low temperatures[4]. If high temperature operation is involved, flash point, oxidation resistance and volatility become the primary factors.

In addition to choosing an oil which will give the desired service characteristics, the final lubricating grease must also be pumpable through whatever dispensing system is used to lubricate the equipment. If oils are used that result in greases which are too viscous or stiff at temperature of operation of the grease-dispensing system, much trouble can result because of the failure of the grease to reach the points to be lubricated. Oil viscosity, however, is only one of the properties of a grease which affect pumpability and slumpability[5].

A further effect of oil viscosity on a grease lies in the tendency to "bleed." This phenomenon is particularly troublesome if an oil of too low viscosity is used. A small amount of "bleeding" is not harmful and some grease technologists feel that such release of oil is necessary. However, a complete breakdown to an oil phase and a soap phase is objectionable and would probably result in equipment failure.

A final requirement of the oil chosen should be its compatibility with the thickener used[6].

THICKENERS USED IN GREASE MANUFACTURE: At least 90% of all lubricating greases manufactured in the United States at present utilize metallic soaps as the thickening agent. For this reason, most of this discussion will be based on metallic soap greases. Examples of other greases being marketed today which contain no metallic soaps would be the asphaltic residuums greases, asbestos lubricants and the more recently marketed silica gel and bentone greases.

The most common present-day metallic-soap-base thickeners are soaps of calcium, sodium, aluminum, barium and lithium. Ordinarily only one metal soap is used in a given grease, although certain mixed base greases such as sodium-calcium are also manufactured.

Since the effect of the metal atom in the soap, contained in the grease, was for a long time considered the predominating factor in determining the characteristics of that particular grease, commercial systems of classification were adopted using the name of the metal as the basis for classification. Some of the chief characteristics that are obtained with the above type soaps are:

1. CALCIUM SOAP GREASES: Calcium greases are variously known as pressure-gun, cup, or lime greases. Their chief characteristic is their insolubility in water. Their soap fibres are very short giving them a smooth and buttery appearance. Most calcium greases are stabilized with a small amount of water to hold the soap and the oil together. Because of this, such greases cannot be used for extended times above 150 - 160 F., or they will lose water and separate. (However, there are some calcium soap greases commercially available today which have been stabilized with organic additives which have proved quite successful at higher operating temperatures.) Calcium greases still represent a large portion of the greases used in the world today because they are cheap and fairly satisfactory for general lubrication of plain bearings in industrial applications at normal temperatures and loads. These greases, subjected to high pressures and/or temperatures in centralized lubrication systems, often separate and clog the system which makes them unsuitable for this application unless operating pressures are low.

2. SODIUM SOAP GREASES: The sodium soap used in soda-base grease is usually fibrous in texture and relatively water soluble. These greases usually have dropping points above 300 F., which allow them to be used at higher temperatures than calcium greases. The fibre length of sodium soap grease can be varied by the method of manufacture. Short-fibre sodium soap greases have their greatest application in automotive wheel-bearing and industrial anti-friction bearing application.

Long-fibre sodium greases are used industrially for lubrication of journal bearings at temperatures above those at which conventional water-stabilized calcium greases can be used.

3. ALUMINUM SOAP GREASES: This type of grease is more nearly a jelly than either of the above and no coupling agents are needed in the manufacture of such greases. They are buttery and have the shortest fibres of any soap used in grease making. They are suitable for lubrication at temperatures up to 180 F., which is a little higher than for calcium greases. They are waterproof and have better tendency to adhere to metal and usually bleed less oil than conventional calcium greases. They are used extensively for lubrication of automotive chassis and for cams, chains and oscillating surfaces where other greases will not cling.

4. BARIUM SOAP GREASES: These were the first of the multi-purpose greases to reach the market[7]. They were introduced to industry about 1940 and started the trend toward the use of multi-purpose lubricants. They are waterproof and have a dropping point of about 375 F. They are very adhesive[7], smooth-to-fibrous in texture and do not soften unduly at temperatures approaching their melting point. They can be used for anti-friction bearing application as well as chassis lubrication.

5. LITHIUM SOAP GREASES: These multi-purpose greases have been introduced to industry even more recently than the bariums and are pres-

ently giving more promise over a wider range of applications and temperatures than barium. They range from buttery to stringy in texture, depending on the oil and fat used and have dropping points of about 350 F. They show excellent water resistance and work stability.

It has not been until recent years that the importance of the fat or fatty acid used in the soap was recognized as having a bearing on the soap structure.[8] It is now a well known fact that animal fats such as tallow and lard, which have been used extensively for grease making, can be of highly variable composition if not controlled by rigid specifications. It was also recognized that many vegetable and fish oils had much more constant composition than animal fats but they did not make hard firm soaps because of their unsaturated chemical structure. By "hydrogenating" these oils, it has been found that very uniform fats can be obtained having excellent soap-fibre-forming characteristics.

ADDITIVES USED IN GREASE MANUFACFACTURE: Except for the stabilization of most calcium soap greases, additives are not necessary in the basic manufacture of greases. However, they are sometimes employed to change or improve their characteristics. Some of the more common types are:

(1) COUPLING AGENTS: In calcium base greases especially, coupling agents are required to effect the formation of the soap-oil structure and to keep the soap and oil from separating after manufacture. The most common coupling agents used for this purpose are water and high boiling organic stabilizers.

(2) LOAD-CARRYING IMPROVERS: Greases that are subject to heavy overloading, high shock loads, or conditions of extreme pressure often require additives to prevent damage to bearings. The usual additives for this purpose are small percentages of lead soaps, chlorinated compounds, sulfurized fats or oils and phosphorous compounds.

(3) OXIDATION INHIBITORS: The oxidation of the soap and/or the oil in a grease can cause rapid breakdown of the grease structure. Oxidation inhibitors to give resistance to oxidation are of special importance in greases used in "sealed-for-life" bearings. For the most part, the more complex amines are used for this purpose.

(4) RUST INHIBITORS: Rust preventive qualities in a grease are sometimes important under severe conditions of operation and storage to prevent bearing and metal corrosion. Some lead soaps and sulfonates have been quite successful for this purpose. Certain sodium soap greases provide natural rust protection because they bind the free water and provide an alkaline reaction.

(5) ANTI-WEAR AGENTS: In many precision bearing applications, especially in instrument lubrication, wear factor is of extreme importance. In such cases, anti-wear compounds are often added to reduce wear to a minimum. Oil-soluble urea or thiourea derivatives are often used for this purpose.

(6) CONSISTENCY IMPROVERS: Additives are sometimes used to reduce the tendency of a grease to soften when worked. This type of additive is one which strengthens the soap structure. Special soaps are often used to produce greases of improved mechanical stability.

(7) HEAT STABILITY IMPROVERS: As mentioned previously, heat stability can be improved in some greases, especially the conventional calcium type, by the use of additives. Calcium greases, which ordinarily break down at 160 F., can be stabilized to operate at temperatures even above their melting point and above the boiling point of water. Glycerine is sometimes used for this purpose.

(8) STRINGINESS AGENTS: Liquid latex or high molecular weight linear polymers are sometimes added to a grease to impart added tackiness or stringiness. Stringiness agents have been considered quite desirable in the lubrication of certain types of tractor rollers for the purposes of keeping the grease on the lubricated part longer.

(9) MINERAL-SOLID ADDITIVES are commonly used in many greases for special operating conditions. These additives form a solid film between the lubricated parts. They are desirable in non-precision applications where extremely heavy loads and intermittent stopping and starting are encountered. Materials in common use are graphite, carbon black, mica, asbestos, lead and zinc. Such additives are not recommended for precision anti-friction bearings.

(10) DYES & ODORANTS: In the past, but practically eliminated from present day manufacture, most greases contained either dyes, perfumes or both. Dyes were used either to make a product distinctive to the trade or during the period when grease-making was an "art" to make the appearance of one batch the same as the next. Perfumes, such as oil of myrbane, were often used to mask the rancid or pungent odors of the fats used in the grease which remained even after saponification was complete.

CHEMISTRY OF SOAP BASE GREASES: Having covered in a general way the various ingredients which go into making a grease, we should cover briefly the chemistry involved in the saponification process in order to understand fully the various manufacturing processes as they will be discussed later on. The chemistry involved in the formation of metallic soaps can become quite complex but the basic reactions remain fundamentally the same regardless of the metal atom used or the fatty material involved.

A metallic soap is formed when a fat or fatty acid is reacted chemically with a metal salt or metal hydroxide. This process is called saponification. Glyceryl tri-stearate, or tri-stearin as it is commonly called, is typical of the material found in animal fat and is probably the most common ingredient found in all ordinary fatty materials. For that reason, this compound will be used as a typical example for our discussion.

A chemical change can easily be made to occur under certain conditions in the presence of water causing the molecule to split to form one molecule of glycerine and three molecules of stearic acid, the fatty acid of tri-stearin, as follows:

Tri-Stearin	plus	(3) Water	yields	(3) Stearic Acid	plus	Glycerin
$C_{17}H_{35}$-COO-CH_2						HO-CH_2
$C_{17}H_{35}$-COO-CH	+	3H-OH	⟶	$3C_{17}H_{35}$-COOH	+	HO-CH
$C_{17}H_{35}$-COO-CH_2						HO-CH_2

By further reacting the stearic acid with caustic soda, the chemical reaction will result in the for-

mation of a molecule of sodium stearate (the metallic soap) and water:

Stearic Acid	plus	Caustic Soda	yields	Sodium Stearate	plus	Water
$C_{17}H_{35}COOH$	+	NaOH	⟶	$C_{17}H_{35}COONa$	+	H_2O

If the tri-stearin is reacted directly with the caustic soda in the presence of water, the splitting action into glycerine and the formation of the metallic soap will be performed simultaneously.

It is interesting to note from the above typical reactions that if fat is used as a basic raw material, glycerine will be left in the finished grease as part of the reaction. If no glycerine is desired in the finished product, the starting fatty material must be in the form of fatty acid.

Although the above reactions only show the most simple saponification reactions, practically any metallic soap desired can be obtained by the proper choice of raw materials and reaction temperatures. In some of the more complex reactions, intermediate by-products, such as sodium chloride or sodium sulfate, might be formed which would, of necessity, have to be removed before making the final grease.

MANUFACTURE OF GREASES: From the standpoint of manufacturing, greases may be classified into four general classes: cold sett greases, heat processed greases, residuum greases, and dispersed greases.

1. COLD SETT GREASES: The cold sett greases are mixtures of calcium soaps of rosin acids and various grades of mineral lubricating oil. They are, in general, one of the cheaper grades of greases. Most axle greases are made by the cold sett method. The popularity of this type of product is diminishing as they can only be used to lubricate rough machinery, launching ways, track curves, etc.

Sett greases are usually made by mixing while cold, or at a temperature of less than 150 F., mineral oil, rosin oil and sett. The sett is an emulsion containing light mineral oil, water, hydrated lime and a small amount of rosin oil. An ordinary kettle with agitators and bottom draw-off is all that is required for the manufacture of these products. A steam jacket on the kettle is not required unless the formulation calls for mixing temperatures higher than room temperature. The above mentioned mix is agitated in the kettle for a few minutes and as soon as it starts to solidify, is drawn off directly into packages. This material is very rarely filtered or worked after solidifying. Making sett greases still falls into the "artist" classification as control over consistency and lumpiness is very poor.

2. HEAT PROCESSED GREASES: The bulk of the greases in use today are processed by heating. This method applies to calcium, sodium, aluminum, lead, barium, lithium, strontium and mixed-base greases. There are several methods used, but the major portion are processed by one of the following methods:

Method 1 — OPEN KETTLE METHOD: The open kettle method of processing grease is probably the oldest method known and there are still large quantities being made in this type of equipment at the present time.

Open kettles for grease making range in size from 100 to 2500 gallons. They can be single-sheet steel or cast iron for direct heating with oil, coal, gas or electricity; or, double shell for heating with steam, hot oil, "Dowtherm" or other circulated hot fluids. The bottom of the kettle should be dished, concave or cone shaped with at least a 6" draw-off for easy removal of the finished grease. The kettle should be provided with two sets of paddles which revolve in opposite directions at different speeds to obtain maximum shear and agitation. Steel scrapers, adjustable for tension and wear are attached to the outer paddles or sweep to completely scrape the inner surface of the kettle.

To manufacture a batch of sodium-soap grease by the open kettle method, the melted fat, caustic soda solution and a portion of the mineral oil are pumped into the kettle, the agitators started and the heat applied. After saponification is completed, the moisture is either completely evaporated or adjusted to the proper percentage. The heat is turned off, the remainder of the oil added with stirring, any desired additives put in, and the batch is agitated until uniform. It is then drawn from the kettle.

Method 2 — CLOSED KETTLE METHOD: The kettles used for this method of grease manufacture are identical in shape, design, and paddle requirements as the open kettle described previously except that the kettle is equipped with a cover and designed to hold internal pressures up to 150 psi. These are rarely designed for direct fire but are jacketed for heating with steam, oil, or other fluids.

With this method, both saponification and finishing are done in one unit. When excess moisture is not produced by the reaction, and when the oil is such that it is not darkened by prolonged heating, everything desired for the finished grease may be charged into the pressure mixer, the unit closed, heated for a designated period after which the steam is turned off and cold water circulated through the jacket until the grease is cool enough to be drawn without losing moisture. With this procedure, nothing is left to the judgment of the operator and, with the same raw materials, there is very little variation between batches.

The above simple procedure is not generally followed, however, since the large percentage of oil in the mix dilutes the reacting chemicals and increases the time for saponification. An alternate method using the same equipment is to heat the reactants and part of the oil under pressure. When the saponification is complete, the pressure is released and the remainder of the oil pumped in.

A third procedure using this equipment, which can be used when very careful control of the moisture content is desired, is to add the oil to the base while still under pressure.

Method 3—TWO-STAGE OPEN & CLOSED KETTLE METHOD: Probably the most efficient method of batch saponification is a combination of a pressure mixer and two open kettles. Only the soap is made under pressure. The pressure kettle is charged with fat, saponifying agent and a very small portion of the mineral oil. The unit is closed, agitator started and steam turned into the jacket to develop an internal pressure of 75 to 85 psi. Saponification takes from fifteen to thirty minutes. On completion of the saponification, the base is blown into one of the open kettles. Most of the moisture from the base is flashed into steam as the

pressure is released. While the oil is being added to the open kettle to complete this batch, the pressure mixer is charged for a second batch. As many as four batches of finished grease can be produced per day with the three kettles.

The use of pressure saponification not only improves grease uniformity but also cuts down on the chance for lost batches and permits less experienced operators to operate the equipment.

Although the above three methods are those most generally used by grease manufacturers, many special types of equipment have been developed either to speed up reaction by the batch process or to develop continuous processes to increase production and lower unit costs. Two of these recent developments have proved quite successful and merit mention at this time as quite possibly such processes will come into more general use in the future.

Method 4—"VOTATOR" METHOD: This process is the only one at the present time which has been perfected for continuous processing of aluminum soap base greases.

Aluminum stearate grease manufacture generally differs from the manufacture of sodium and calcium greases in that the manufacture of the aluminum stearate is usually carried on as a separate process without the presence of oil. Usually stearic acid and caustic soda are reacted in the presence of water to form water-soluble sodium stearate. Then, by double decomposition, the sodium stearate is reacted with a water solution of aluminum sulfate or alum to form the water-insoluble aluminum stearate. Since sodium sulfate is a resultant unwanted by-product of the reaction, the aluminum stearate must be washed free of it and dried prior to the formation of the grease in oil.

The early method of aluminum grease manufacture was to mix the dried aluminum stearate with the oil selected in an open kettle to temperatures of 275 to 350 F. After complete solution of stearate and oil was reached, the solution was pumped into large pans, 6 to 8 inches deep, and allowed to cool. During the quiescent cooling period, gel formation took place and the resultant product was transferred into drums and shipped to the customer. The chief difficulty with this method was that the grease formed was of different consistency in the center of the pan than at the edges. Later developments resulted in cooling in smaller pans under controlled cooling conditions and then mixing the grease from a number of pans to get a more consistent final product. Here again, however, the product was a mixture of different gel structures—some hard and some soft—which naturally would have a bearing on the stability of the final product.

The "Votator" process consists essentially of two controlled temperature heat exchangers; one, for heating the aluminum stearate—oil slurry to give an oil solution and the other, to cool the solution to a predetermined critical temperature prior to the quiescent gel forming stage. At this critical temperature, the cooled solution can be pumped into gelation tanks rather than pans with relatively little change in consistency of final product in the various parts of the tank. Continuous manufacture is effected by the use of two vacuum slurry mixing tanks for premixing the cold oil and aluminum stearate before pumping to the heating votator. While the slurry is being mixed in one tank, the slurry is being pumped from the other. The time required in the gelation tanks varies with the properties of the base oil used from 15 minutes to several hours. Packaging can be done directly from the gelation tanks or, further working can be done as desired. The development of this method of aluminum stearate grease manufacture has led to more uniform and stable aluminum stearate greases.

Lithium greases can also be prepared in this equipment using preformed lithium soap. However, in most cases, a gelling period is not required and the grease can be pumped directly from the cooling Votator into the package.

Method 5—STRATFORD METHOD: The Stratford Engineering Company has developed a contactor for grease saponification in which calcium, sodium, or lithium soap grease can be finished in a fraction of the time required in normal kettle manufacture. It is claimed that a complete batch of calcium base grease can be made in one of these units in one and one-half hours and sodium base grease in two and one-half hours.

The Stratford Contactor is composed of a double cone shaped vessel. Both cones are jacketed for oil heating and can be either open or covered for pressurizing. The ingredients are charged into the inner cone and agitated with double-motion scraper-type agitators similar to those described in kettle type manufacture. An impeller type pump is installed at the bottom of the cone to pump the reacting ingredients through the annular space between cones and back into the inner cone. Both cones are heated by oil circulated through the jackets, and, because of the very rapid heating and tremendous agitation, a uniform batch can be completely saponified in a very few minutes.

RESIDUUM GREASES: In the strict sense of the word, these products are not greases at all, but usually extremely adhesive blended or compounded oils. They are commonly known as gear shields, or open-gear lubricants and consist chiefly of blends of viscous, black oils and may contain crude oil still bottoms. They are made in a wide variety of consistencies varying from products which flow freely at ordinary temperatures to those which are so viscous they will support considerable weight, and require heating for application. Many of the present day gear shields contain additives such as fats, graphite, powdered lead, mica, etc., to give them special characteristics.

This classification of product is usually blended in an open top kettle which is either steam heated or direct fired. No problems are involved in the manufacture other than simple heating and stirring to obtain a uniform blend.

DISPERSED GREASES (Non-Soap Base): This is an entirely new classification of grease and covers non-soap base greases such as the silica gel and bentone thickened lubricants. These have been in commercial use for over three years.

Since these lubricants contain no soap, heating to complete saponification or to melt a soap is not required in their manufacture. Grease making is merely a matter of properly dispersing the bentone or silica gel in the oil. This cannot be done in a

kettle by ordinary paddling as the minute particles or platelets will not separate. It is necessary to use equipment of the colloid mill type, where extreme shear and turbulence separates the platelets and permits them to be wet by the oil. Colloid mills which operate at clearances of .001" to .002" between working surfaces are used to manufacture this type of grease.

Additives of the type used in soap base greases can be used in the manufacture of this class of lubricants as well. Usually such additives are introduced in the manufacture at the same time as the oil and thickner is made into a cold slurry prior to dispersing through the mill.

GREASE FINISHING: In the early days of grease manufacture, once a batch was brought to the proper consistency, the grease was drawn or pumped directly to the package with little consideration given to any final finishing. Now, however, the manufacturer is as particular of the proper finishing of his product as he is of the raw materials that go into the batch for saponification.

Most grease plants have filters or screens in various stages of the process to insure the elimination of solid particles. Nearly all saponified greases are pumped from the kettle through fine grease or filter presses to remove small hard lumps of soap base, gritty particles, or black carbonaceous particles which might be impurities in the raw materials or result from local overheating in the kettle. Screens as fine as 60 mesh are used for this work.

Certain types of grease also require further cooling before being packaged. Kettles equipped for water circulation in the jacket are frequently used. If such equipment is not available, grease chillers can be installed at the outlet of the kettle. These are usually double walled heat exchangers where the grease is pumped through the inner wall and cooling water or brine pumped through the outer wall. Open cooling trays, as described in aluminum stearate grease manufacture, are frequently used for cooling of aluminum stearate and smooth soda base greases.

As a final finishing step, many greases are now "milled" or "homogenized" prior to final packaging. This is done chiefly to obtain a more uniform product and to give a worked consistency to the grease. Many mills have a tendency to introduce air into the product during working and it is necessary either to preform the milling operation in a vacuum or to use air eliminators to de-air the final product before packaging. Many grease workers are on the market today which will do a satisfactory job of working and de-aerating. Among the most commonly used are the Cornell Grease Homogenizer, Charlotte Colloid Mill and Morehouse Mill.

TRENDS IN GREASE LUBRICATION: Even though intensive research on greases has only been going on for the past ten or fifteen years, there are definite trends in grease technology which makes it possible to make some predictions as to what can be expected in the future. In review, conventional calcium greases were waterproof, but could not be used generally at temperatures above 150 F. Their buttery structure and low top operating temperature made them unsuitable for anti-friction bearing lubrication. Aluminum greases were waterproof, more adhesive than calcium greases, and could be used at slightly higher temperatures but were still unsuitable for the lubrication of anti-friction bearings for the same reasons. While the fibre structure of sodium greases and their higher operating temperatures made them suitable for anti-friction bearings, they were soluble in water to various degrees and could not be used satisfactorily in applications where water was present. For low temperature applications special low viscosity oils had to be used with the above products to permit pumping through dispensing systems. With these oils it is often difficult to make a satisfactory soap structure.

Faced with these limitations of the available greases, grease research placed it emphasis on products which would have wider applications and make reduction in inventories possible. The aim was—and still is—to come up with a product that will come closer and closer to approaching the category of "all-purpose." One grease to handle every application.

Only a decade ago, the first multi-purpose grease was marketed. This was made from a complex barium soap. This product was waterproof and had a dropping point in the neighborhood of 400 F. It was fibrous in nature, and could be used for anti-friction bearing lubrication as well as general lubrication. It was now possible to use one product for the entire grease lubrication of a passenger car or truck. It was the first step in the category of multi-purpose greases[7].

The next step toward the ultimate was the newer lithium greases. Although top operating temperatures are not as high, these products have better low temperature characteristics as a general rule[3]. The lithium greases are not as water-repellant as barium greases and while quite water resistant, they have the ability to absorb some water which is advantageous. The main difficulty with the early lithium greases was their tendency toward separation of the soap and the oil. More recently, more complex soaps of lithium, such as the lithium hydroxy stearates have been developed which are bringing the lithium base greases closer and closer to the ultimate multi-purpose product.

The most recent developments in multi-purpose grease research have been toward the non-soap base products such as the silica gels and bentones. Very little silica gel grease has been marketed to date because of its high susceptibility to breakdown by moisture. Considerable work has been done to make them more water resistant and when this is finally accomplished this group of products will take their place with the good multi-purpose lubricants.

The bentone greases have been marketed as multi-purpose lubricants for a little over three years and are rapidly finding a place as multi-purpose lubricants. This class of grease has no melting or dropping point. Therefore, the top operational limit of a bentone grease is controlled by the rate of oxidation of the base oil. Pumpability and stability are good—and in most multi-purpose applications consumption is lower than with the soap base greases. This compensates to some degree for their higher cost. Although, the non-soap base greases have been marketed for only a short time,

there is no question as to their becoming a definite factor in the development of improved grease lubrication.

The silicone greases, although not considered multi-purpose lubricants, were first introduced about eight years ago, and have been another step in improved grease formulation. These products are carbon-black or metallic-soap-base thickened silicone fluids. These fluids are silica-organic materials possessing high stability together with the pronounced water repellency. The silicone greases have been especially successful in high temperature applications. Their use, however, has been limited to special conditions due to their very high cost and lack of lubricity for steel-on-steel under heavy loads or high speeds.

Grease technologists have not as yet reached the ultimate in "all-purpose" greases. Rapid strides have been made in the last few years and there is still more work to do. The truly "all-purpose" grease with no faults will probably never be found but if it should be, it will have the following characteristics:

(1) It will be pumpable and lubricate bearings at temperatures as low as 100 F. below zero.

(2) It will have no melting point, and not oxidize or break down at any temperature that moving parts must be lubricated.

(3) Consistency will not vary over the entire range of operating temperatures. One grade will be used for all applications.

(4) It will be water resistant but yet have the property of absorbing moisture of condensation to resist tendency toward corrosion.

(5) It will remain unchanged chemically or physically in the container in storage as well as on parts which have been lubricated and stored before use.

(6) It will be mechanically stable and neither lose consistency nor get harder when operating in bearings.

(7) It will have sufficient film strength to withstand shock loads and lubricate when the lubricated parts are operating under high pressures.

As this ideal is approached — greasemakers, salesmen, suppliers, and the general public can expect fewer but better greases designed for wider and more general applications. As the choice of grease products becomes more simplified, the advantages of grease lubrication will become more generally recognized.

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Annual Meeting Abstracts

The following abstracts of papers (those which arrived too late for publication in the April '53 LE) presented at the 1953 ASLE Annual Meeting, Hotel Statler, Boston, April 13-14-15, are published herewith for general information. They do not necessarily represent the final opinions of the authors and are subject to revision when the complete papers are published.

FRICTIONAL BEHAVIOR OF POLYETHYLENE, TEFLON & HALOGENATED DERIVATIVES

by R. C. Bowers, W. C. Clinton & W. A. Zisman
Surface Chem. Branch, Naval Research Lab.

The static and kinetic frictional properties of a group of unplasticised linear polymers and copolymers as well as films of Teflon were investigated in a Bowden-Leben "stick-slip" machine. These solids are derivatives of polyethylene containing various proportions of fluorine or chlorine. The results obtained with various methods of surface preparation for polymer sliding on polymer, steel on steel, and polymer on steel are discussed with reference to the increasing halogen content, the transfer of plastic films during sliding, the semi-plastic nature of the polymers and their deformation during sliding. Some of the theoretical and practical applications are considered.

THE SIGNIFICANCE OF LABORATORY TEST DATA ON GREASES

by A. E. Baker, E. G. Jackson & E. R. Booser
Thomson Lab., General Elec. Co.

The fundamental nature of various laboratory bench grease tests are reviewed, with particular consideration of their significance in predicting and evaluating field performance. Penetration, oil content and viscosity, oxidation, shear stability, dropping point, corrosion tests, bleeding and evaporation, and wear tests are reviewed and related to performance in ball bearings and various other mechanical devices.

Although much work remains to be done in devising improved test methods which will better characterize grease structure and stability, present procedures are capable of providing valuable guidance in grease selection provided the correct interpretation of the laboratory test data is applied.

THE TESTING OF USED OIL

by C. L. Pope & D. A. Hall
Eastman Kodak Co.

Since the proper functioning of lubricants is of greater significance than the original cost, testing of used oils is valuable as a means of determining when an oil in use will become detrimental so that a change can be made just before the occurence of a breakdown.

Tests which have proven their merit for the evaluation of used lubricants are presented with particular emphasis being placed on their advantages and disadvantages in furnishing usable results. These tests involve a study of oil properties of oil contaminants and the ways of detecting them, as well as methods of determining what amounts can be tolerated in a given machine.

VISCOSITY STUDIES OF FLUID LUBRICATION AT HIGH PRESSURES

by L. B. Sargent, Jr.
ALCOA Research Lab.

A brief resume of the types of viscometers used in investigating the effects of high pressure upon the viscosities of fluid lubricants is presented. Representative data from the literature and original work are used to emphasize the differences in high pressure-viscosity behavior of various types of fluid lubricants. These data will be presented mainly in the forms of graphs so that the differences emphasized are rather obvious. For example, the different behaviors of petroleum oils, fatty oils, and synthetic fluid lubricants will be indicated.

The most important point in the paper will be an at-

(Continued on page 161)

THE MECHANISM OF FRETTING*

by I-Ming Feng & B. G. Rightmire
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Dr. Feng received his B.S. degree in Mechanical Engineering from Chiao-Tung University, China, in 1946; he received his M.S. degree in 1948 and his Ph.D. degree in 1952 from the University of Michigan. Since 1950 he has been engaged in research on solid lubricants at the Lubrication Laboratory of the Massachusetts Institute of Technology.

Dr. Rightmire received his undergraduate training at Ohio State University, and a doctorate in mechanical engineering from M.I.T. in 1941. He has been at M.I.T. since 1935 and is at present associate professor of mechanical engineering, in charge of the Lubrication Laboratory.

ABSTRACT: The purpose of this paper is to present a mechanism of fretting based on the new mechanism of wear suggested by Feng. Fretting begins with ordinary wear. It then goes through a shifting period in which accumulation of trapped wear particles shifts the wear action gradually to abrasive action. Finally it reaches the abrasion stage in which damage is almost entirely caused by abrasion. Experimental results obtained by the authors and also other investigators are cited here for supporting this mechanism of fretting.

INTRODUCTION: The so-called "Fretting Corrosion" is merely a special case of wear, in which, because of the small amplitude of relative motion, wear is highly concentrated in the areas of actual contact, the wear product is trapped and accumulated between contacting areas with the result of accelerating the wear by abrasion, and moreover oxidation of wear particles further accelerates the abrasive action. In other words, concentrated mechanical wear is the primary cause of fretting, and accumulation of trapped wear product and oxidation of wear particles are the secondary causes of fretting.

THE MECHANISM OF FRETTING: To explain the mechanism of fretting in detail, the surface finish will first be considered. It is well known that an ordinary flat surface is not a geometrical plane, but that a large-scale waviness exists which is caused by the machine or the method used for producing the surface. Fig. 1(a) illustrates schematically large-scale waviness, which gives the surface elevated regions and depressed regions. Superimposed upon the large-scale waviness is the macroscopic roughness which gives the surface a large number of high spots as shown in Fig. 1(b). Furthermore, these high spots have the roughness of their own in microscopic scale. The macroscopic and miscroscopic roughnesses depend on the cutting tool and the technique used in finishing the surface.

If two surfaces are brought together, a few high spots will come into contact first. Increase in load will bring more high spots into contact. The contacting high spots are not uniformly distributed over the whole surface, but are grouped into a relatively few companies because of the large-scale waviness as illustrated by Fig. 2.

Consider a single pair of contacting high spots. Fretting begins with metallic wear. The mechanism of wear as suggested by Feng[1] is briefly as follows: When a pair of actually contacting high spots carries a normal load that is great enough to cause plastic deformation, the interface of the contacting high spots will be roughened by plastic deformation as shown in Fig. 3(a). This roughening of the interface produces a mechanical interlocking effect which strengthens the interface in resisting tangential force. The application of a tangential force will shear off the peak of one of the pair of high spots, instead of separating the contacting high spots along their original interface. The small piece of metal sheared from one high spot becomes a loose wear particle as shown in Fig. 3(b), if there is nothing to keep it adhering to the other high spot.

Picture a case I in which the surrounding atmosphere is inert, and the relative motion is unidirectional or the amplitude of the alternating motion is very large. The mechanism of formation of loose wear particles described above is responsible for the entire wear, because the loose wear particles have under these circumstances a good chance to leave the space between the surfaces and hence produce very little abrasive wear. Curve I in Fig. 4(a) gives the usual relation between the wear and distance of travel (or duration) for Case I. The portion A_1B_1 of the Curve I is a straight line. The slope represents the final rate of wear, which, in this case of no abrasive action, is relatively small.

In a hypothetical Case II for which the relative motion is oscillatory with very small amplitude, the wear product will be trapped and accumulated among the contacting regions of the two surfaces, and produce abrasive action. In this case, the surrounding atmosphere is also assumed to be inert and the loose wear particles therefore do not change into oxide. The rate of weight loss in this case will be larger than that in Case I. For this Case II, the relation between wear and distance of travel is represented by Curve II in Fig. 4(a).

For a hypothetical case (Case III), if we assume in addition to the very small amplitude of the alternating motion, that the loose wear particles are oxidized instantly when they are formed, then the hardness of the oxide may further accelerate the abrasive action and give a larger rate of

*Sponsored by the ASLE Technical Committee on Lubrication Fundamentals and presented at the ASLE 8th Annual Meeting, Boston, April 15, 1953.

weight loss than in Case II (Compare Curves II and III in Fig. 4(a)).

In the ordinary case (Case IV) the wear particles are not oxidized instantly, and therefore those that are in contact with the surfaces of the specimens and producing an abrasive effect are distributed among metallic, partially oxidized, and fully oxidized states. The rate of wear will therefore be greater than that in Case II but smaller than that in Case III. The Curve IV, which represents weight loss vs. distance of travel for this Case IV, falls in between Curves II and III. Therefore, $W_4=c_2W_2+c_3W_3$, where W_2, W_3, and W_4 are respectively the weight losses for the Cases II, III, and IV, and c_2 and c_3 are positive coefficients which must satisfy the condition $c_2+c_3=1$. The effect of the surrounding atmosphere on W_4 is isolated in the coefficients c_2 and c_3, since W_2 and W_3 are independent of atmosphere. In the one extreme of an inert atmosphere, $c_2=1$ and $c_3=0$. In the other extreme of an oxygen atmosphere and very low speed (complete oxidation), $c_2=0$ and $c_3=1$.

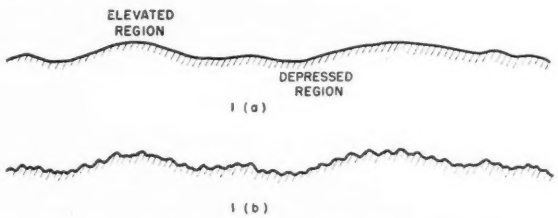

Fig. 1(a) (top) Surface finish — large-scale waviness which gives the surface elevated and depressed regions.

Fig. 1(b) (bottom) Surface finish — macroscopic roughness which is superimposed upon the large-scale waviness.

THE SHAPE OF WEAR VS. DISTANCE OF TRAVEL CURVE: A discussion of the shape of the Curves I, II and III will bring out some details about the mechanism of fretting. As has been discussed before, the contact between two surfaces is established only through a large number of scattered high spots that are grouped into a few companies. The companies of high spots are located in the elevated regions formed by the large-scale waviness of the surface. In Case III, we assume a very small amplitude of relative motion and instant oxidation. Because of the small amplitude, the oxide particles are trapped in the spaces among high spots as shown in Fig. 5(a). As the oxide particles accumulate, these spaces are soon filled, and from that time on, the individual areas of contact in one company integrate into a united area, as shown in Fig. 5(b). These united areas will develop into large and deep pits as the fretting process proceeds. This process is described as follows: During this period, the rate of weight loss is high because the abrasive action is most effective when the layer of oxide particles is thin. The abrasive action itself, however, thickens the layer of oxide particles. As this thickness increases, the abrasive action becomes less effective, because a portion of the relative motion is lost inside the layer of abrasive particles. Thus the slope of Curve III, which represents the rate of wear, decreases as the time increases. Eventually the oxide particles begin to escape into the adjoining depressed regions associated with the large-scale waviness of the surface (Fig. 5(c)). A redistribution of normal stress over the contact region accompanies this outflow of oxide particles, the stress near the center becoming greater, while that at the periphery is reduced. As a result, the center of the region is subject to stronger abrasive action and, therefore, deepens more quickly than the periphery, gradually assuming a curved shape, as shown in Fig. 5(d). Furthermore, the escaping oxide particles will gradually fill up the depressions among adjacent elevated regions where pits have developed, and finally a number of neighboring pits will merge into a single large one. As this process is repeated, the pits will tend to become fewer in number but larger and deeper in size, and the layer of oxide particles will become thicker and thicker. When the layer becomes comparatively thick, further increase in thickness has less effect on decreasing the abrasive action. This explains why the rate of wear of the Curve III decreases in the portion OA_3 and finally reaches a steady value as represented by the straight portion A_3B_3.

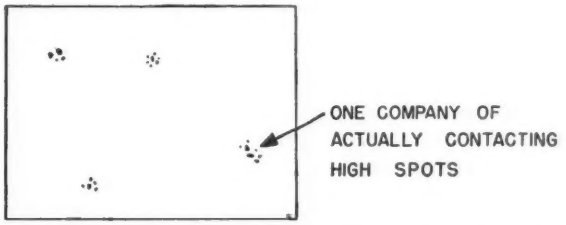

Fig. 2 Non-uniform distribution of contacting high spots which are grouped into a few companies.

In connection with the process of pit formation just described, it is important to include the effect of the increase in volume of an iron wear particle when it is oxidized. This volume increase works along with the smallness of the relative motion in tending to concentrate the damage near the companies of points where the two surfaces make contact during the initial stage of fretting.

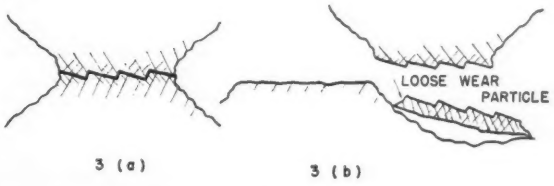

Fig. 3(a) (left) Mechanism of wear — roughening of the interface of contacting high spots producing a mechanical interlocking effect.

Fig. 3(b) (right) Mechanism of wear — formation of a loose wear particle.

The explanation for Curve II is essentially the same as for Curve III. The only difference between these two curves is the rate of wear, which is influenced by the hardness of the particles. The finding by Sakmann and Rightmire[2] that hard oxides produce greater damage is in good agreement with this conclusion.

The relationship among Curves II, III, and IV is expressed by Eq. (1). It is obvious that Curve IV will have the same general shape as Curves II and III.

Although Curve I has a shape similar to the other curves in Fig. 4, the explanation of the shape is different. The details are given in Ref. 3. To explain briefly, the high rate of wear at the beginning is due to poor distribution of load over a relatively small number of contacting high spots. Better distribution of load is achieved through the wear process itself. As wear progresses, therefore, the rate of wear decreases until the final load distribution is reached, giving a steady rate of wear.

In all cases, the weight loss at the very beginning is produced by roughening of the interface and shearing of the peaks of high spots. In Case I, the same mechanism keeps on working, because no accumulation of wear product occurs. In Cases II, III, and IV, accumulated wear product covers the contacting regions in a very short period, after which the wear is caused by the abrasive action of the wear product. During a short period at the very beginning, the wear mechanism thus shifts from shearing to abrasive action. The rate of wear probably increases during the shifting period because the abrasive action is presumably more violent than the shearing. Fig. 4(b) shows the probable shape (the shape agrees with the experimental data recently obtained by Feng. The detailed results will be published later.) near the origin of Curves II, III, and IV.

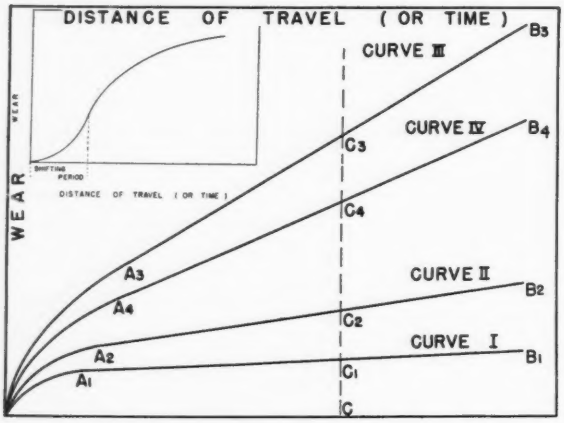

Fig. 4(a) Curves illustrating the effect of distance of travel on wear under various conditions.

Fig. 4(b) (inset) Probable detail of the shape near the origin of curves II, III and IV in Fig. 4(a).

REDUCING AND STOPPING FRETTING DAMAGE: Concentrated mechanical wear is the primary cause of fretting, since the latter is initiated by mechanical wear concentrated in the localized areas of actual contact. If mechanical wear can be prevented entirely, fretting will not occur. One way to prevent the initiation of mechanical wear caused by vibration is to eliminate the relative motion between the surfaces. This can be accomplished by increasing the normal load to such an extent that the external disturbance is completely absorbed elastically in the specimen and machine parts. The same end can also be reached by reducing the external vibration or other disturbances. Feng has performed experiments which yielded results in good agreement with this conclusion. One of such experiments is described briefly as follows: The same testing machine as the one used in obtaining data in Ref. 5 was used. A load of 1000 lb. was applied to the SAE 1018 specimens having an apparent area of contact of 0.184 sq. in. An external oscillating disturbance having a frequency of 540 cpm was applied for 67800 cycles at room temperature. This disturbance that would produce a relative slip of 0.0013 in. under no load was completely absorbed elastically in the specimen and machine parts, and produced no detectable weight loss.

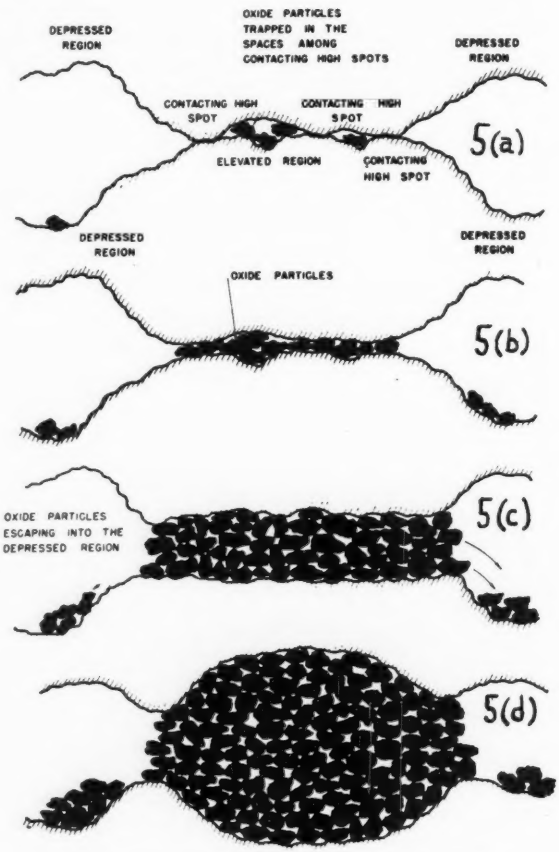

Fig. 5(a) Formation of large and deep pits — accumulation of oxide particles in the space among the high spots.

Fig. 5(b) Formation of large and deep pits — integration of a company of high spots into one single united area, after the space among the high spots is filled by oxides.

Fig. 5(c) Formation of large and deep pits — spilling of oxide particles into the adjoining depressed regions.

Fig. 5(d) Formation of large and deep pits — curved shape of the large pit as the result of stronger abrasive action acting in the central region.

The external disturbance can also be absorbed elastically by inserting such material as rubber between the contacting surfaces. An experiment was carried out by Feng under the following conditions: The same testing machine mentioned above was used. A load of 1000 lb. was applied to two pairs of SAE 1018 steel specimens, one pair with a thin sheet of rubber inserted between the testing surfaces and another with a thin sheet of nylon. An oscillatory disturbance having a frequency of 540 cpm was applied to the specimens for 67800 cycles at room temperature. Without the inserted thin

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A NEW PERFORMANCE TEST FOR CUTTING FLUIDS*

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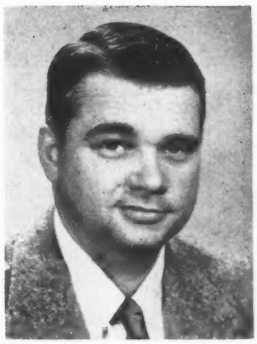


Mr. Stokely is a graduate of the University of Michigan in chemical engineering and metallurgy. Employed by the California Research Corp. as Senior Research Engineer, he is in charge of laboratory performance testing and field testing of industrial and automotive lubricants other than crankcase oils. For the past fifteen years he has been active in the research field of lubrication and metallurgy.

ABSTRACT: This paper describes a laboratory performance test for cutting fluids which correlates well with field performance. It permits rapid evaluation of the effect of additives at various concentrations, as well as direct comparisons of finished cutting fluids. A number of interesting charts show the effects of various classes of additives on product performance, effect of increasing additive concentrations, comparisons of soluble oil emulsions at various dilutions and soluble oil emulsion versus compounded cutting oils.

The rapid development of outstanding new lubricants by the petroleum industry in recent years is due in no small part to the development and use of laboratory performance tests. Such tests may be arbitrarily defined as those which closely duplicate the major performance requirements of a product and may in fact be carried out under conditions which stress the product beyond the demands of normal service.

Field testing must be limited to products that approach complete development in all respects. This includes not only major performance characteristics but also all the many special "minor" requirements, lack of any one of which may result in failure of an experimental product which might otherwise have exceptional merit. Improvement of a product with respect to many characteristics such as color, odor, viscosity, foaming tendency and other qualities is extremely difficult to accomplish after the product has been taken to the field for testing, but most of these properties can be easily altered or improved by rather simple changes if the necessity for change can be learned early in the development of the product in the laboratory. Since the control of variables in field testing is notoriously difficult such tests are generally long and time consuming.

In contrast to this, a laboratory test which correlates with the major service performance requirements permits rapid and systematic development of a new product. Some of the advantages afforded by such a laboratory performance test are: (1) A wide variety of additives essential to performance may be evaluated while all other variables are kept under control. The optimum proportion of performance and special additives may be rapidly determined and several hundred additives may be evaluated in less time than that required to test one product under the poorly controlled conditions characteristic of field tests. (2) A wide variety of base oils and base oil blends may be studied. (3) Rapid evaluation of the important mechanical or machine variables affecting performance. In the case of cutting fluids these include coolant volume, tool angles, tool preparation, cutting speeds and feed rates. (4) It permits evaluation of the effect on performance of special additives used to prevent rusting, foaming, storage instability at either low or high temperature. (5) Permits "wildcatting" with completely new types of additives.

The advantages in the development of new and improved products which this type of laboratory testing affords explains the persistence of research men in trying to develop laboratory performance or functional tests in the development of new products.

The development of a laboratory performance test for metal cutting fluids has been a slow process and has extended over many years with relatively little success. An entire book by O. W. Boston[1] has been published listing over four thousand abstracts of papers in this field alone. In spite of this lack of success, the importance of the advantages to be gained both in the field of cutting fluid development and for evaluating machinability of metals are so great that many attempts have been made to develop such a test. A successful test for cutting fluids could be used to evaluate machinability of metals by maintaining the lubricant as a constant. Conversely, a successful test for metal machinability could be used to evaluate cutting fluids by keeping the metal constant and varying the cutting fluid.

Previous efforts to develop cutting fluid performance tests have employed almost every shop tool that is normally used for production work. These include turning, drilling, milling, shaping, planing, sawing and broaching machines. As early as 1907, F. W. Taylor[2] had published the results of twenty-five years of research on metal cutting, employing essentially a lathe test, measuring tool life. The same type of lathe test has been employed by many other investigators and is still used today[3]. One of the major difficulties in a lathe test is the large size of test specimen that must be employed. It is extremely difficult to obtain test billets of large size which are uniform in metallurgical structure. In addition, the test equipment is massive, expensive and requires a highly skilled operator. The large number of variables introduced by the shape of the lathe cutting tool alone (six cutting angles, the nose radius, the tool alloy and

*Presented at an ASLE Northern California Section Meeting.

the manufacturing source are examples) makes this test method inherently complicated.

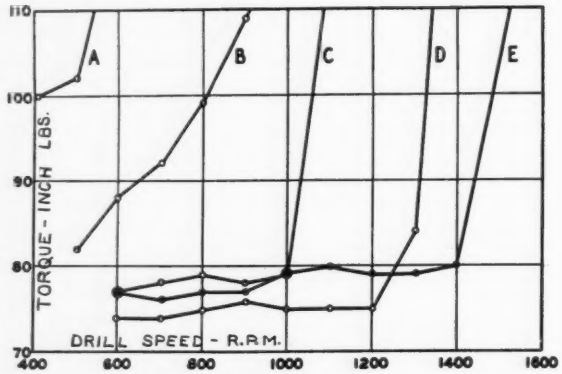


Chart 1 Performance comparison of cutting oils. A: Base mineral oil, B: Sulfurized A, C: B+ oiliness additive, D: B+ E. P. additive, E: D+ oiliness additive.

In contrast to lathe tests, the drill press has attracted many investigators because of the relative simplicity of the tool shape and the small amount of material consumed, thus greatly simplifying the problem of maintaining uniformity of materials. The measurement of forces is also much simpler in drilling than in turning.

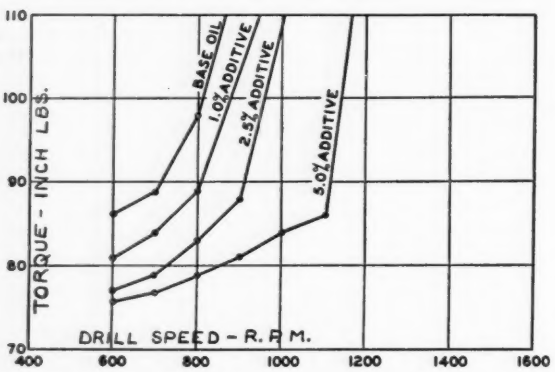


Chart 2 Selection of optimum amount of performance additive.

A careful survey of various types of cutting tests was made to determine what new approach or what additional control of variables might be required for the development of a successful test machine. After careful study it was concluded that certain changes and improvements over previous work might greatly increase the effectiveness of drilling tests.

Among the essential improvements were the following: (1) Careful metallurgical selection of test metals to eliminate non-uniformity. (2) Use of power feed instead of dead weight loading to prevent work hardening of the test metal. This work hardening changes the machinability of the metal even as the hole is being drilled. (3) Precision sharpening of drills to eliminate or minimize drill variables. (4) Ample power and complete flexibility of speeds and feeds. (5) Extreme sensitivity of instrumentation. (6) Standardization and control of motor speed and the torque and efficiency of the bearings and spindle of the test machine so that the measurement of the cutting torque would not include other extraneous factors.

The problem of providing the necessary power and flexibility of speeds and feeds was solved initially by employing a giant six foot swing radial drill press. An electronic measuring device measuring the actual output torque at the specimen was employed to record changes in torque as drilling progressed.

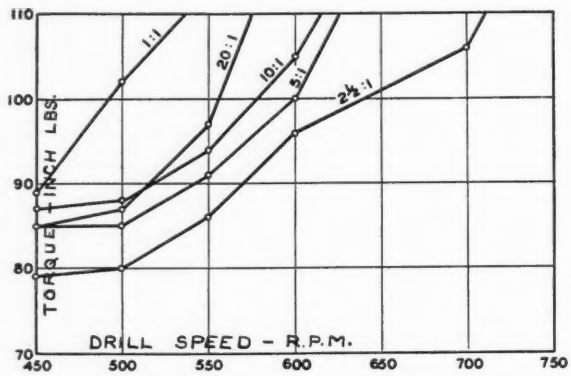


Chart 3 Effect of soluble oil emulsion strength on performance.

Even with adequate test equipment and measuring devices it is still necessary to develop a test procedure which will evaluate oils of known performance in the same order as their performance in the field. The test must be severe enough to show a wide spread between good and poor oils, but not so severe as to distort product service requirements. Finally, the reproducibility must be good enough so that small differences between oils are not exaggerated by a wide spread in test results.

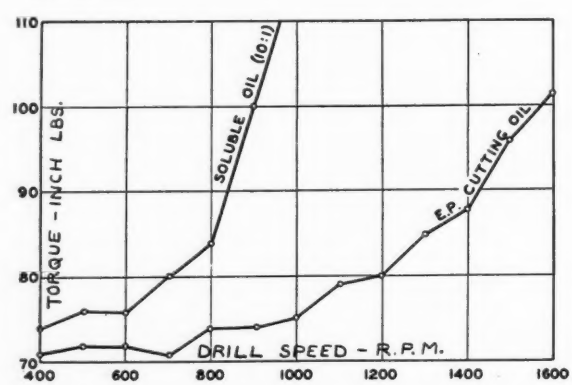
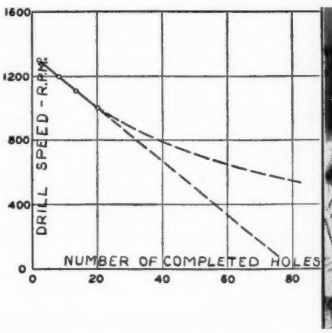


Chart 4 Performance comparison between soluble oil at 10:1 & E.P. type cutting oil.

The text procedures which were developed furnished data of the nature indicated by Charts 1 through 5. A "breakdown" type of test was developed in which a series of holes of constant depth is drilled into the test block at constant feed rate with a precision sharpened drill. Drilling speed is increased either 50 or 100 rpm for each hole. As the severity of the cutting operation is increased, the torque requirement goes up and use of the less effective oils results in rapid tool failures. Eventually, speeds are reached at which even the best oils will not prevent failure of the drill. The data are then plotted as shown in Charts 1 and

2 to show the torque curve and the final speed at which failure occurs for any given oil.

Individual torque curves are recorded automatically for each test hole by electronic instrumentation and the maximum torque plotted. At the lower speeds the torque curve has a rapid initial rise and then levels off. At higher speeds the curve becomes steeper and drill failure is indicated by a sudden sharp peak on the torque curve. The drill, when examined at this point, will show the corners worn or burned off. If not stopped almost instantly the end of the drill will fuse.



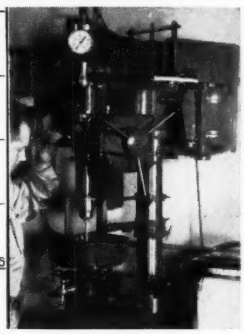


Chart 5 (left) Selection of production drilling conditions.

Fig. 1 (right) Drilling torque tester for cutting oil and soluble oil research.

As a final step in the evolution of this test, it was found possible to develop a smaller laboratory tester which incorporates the essential features of the big factory drill press with even greater flexibility of speeds and feeds. A picture of this test machine is shown in Fig. 1. This machine provides any desired speed from 100 to 4000 rpm and any desired feed rate from 0.004 in. to 0.020 in. per revolution by 0.002 in. steps.

Typical results obtained with this test equipment are shown in Charts 1 and 2. Chart 1 shows the improvement that can be made in a base mineral cutting oil by the use of proper additives. Chart 2 shows the effect of increasing proportions of one type of additive.

The test can also be used to select the soluble oil emulsion strength which gives optimum performance, as shown in Chart 3, or for comparing the relative effectiveness of soluble oil emulsions versus cutting oil under severe conditions, as shown in Chart 4.

Other modifications of the test procedure permit evaluation of tapping lubricants and the selection of optimum production drilling conditions (Chart 5). By maintaining the lubricant constant, the machinability of various metals may be determined by the same basic test procedure previously described.

The final proof of a laboratory performance test is correlation with actual service. We have found, over a period of several years, that the performance of cutting fluids in the field can be accurately predicted with this test, not only for drilling but also for other cutting operations. When this test was first employed to rate our regular cutting fluids, it evaluated them substantially in accordance with the proportions and types of compounding employed. There was one startling exception — an oil which had been modified by the addition of a somewhat different type of extreme pressure compounding. This was found by the drilling torque test to be outstandingly superior to other compounded premium grade oils then on the market. This result appeared to raise a considerable question as to the validity of the test until the service records were examined and it was found that in one year this particular oil had risen to first place in our cutting oil sales.

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New Members

ADAMS, K. W., Atlas Steels, Ltd., Welland, Ont., Can.
ASHLEY, C. H., Socony-Vacuum Oil Co., Buffalo, N. Y.
AUSTIN, C. L., West Side Mach. Wks., Inc., Kansas City, Kan.
BARTH, V. C., Chgo. Northwestern Ry. System, Chgo., Ill.
BARTLETT, T. H., Amer. Brake Shoe Co., Chgo., Ill.
BASSETT, F. H., Socony-Vacuum Oil Co., Inc., Indpls., Ind.
BERGETHON, O. M., N. H. Ball Bearings, Inc., Peterborough, N. H.
BOLT, A. V., Alum. Cooking Utensil Co., Pittsburgh, Pa.
BONNEVILLE, H. W., Carrier Corp., Syracuse, N. Y.
BORRELLI, A., The Bassick Co., Bridgeport, Conn.
BULLEN, J. E., McCulloch Motors, Inc., L. A., Calif.
BYRNE, T. L., Sinclair Refg. Co., N. Y., N. Y.
CAHILL, J. A. JR., Alemite Co. of E. Pa., Phila., Pa.
DOHL, F. M., Dee Engrg. Co., Cromwell, Conn.
DOLAN, F. J., Amer. Pulley Co., Phila., Pa.
DREHER, J. L., Calif. Research Corp., Richmond, Calif.
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FINLAY, W. P., Leeds & Northrup Co., Phila., Pa.
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GALL, L. F., Link-Belt Co., Colmar Plnt., Colmar, Pa.
GALL, R. W., Swan-Finch Oil Corp., Dayton, Ohio.
GAYNOR, L. E., Amer. Oil Co., Baltimore, Md.
GERACE, A., I.T.E. Circuit Breaker Co., Phila., Pa.
GINDIN, E., Downingtown Paper Co., Downingtown, Pa.
GOETSCH, H. C., Motor Oils Refg. Co., Lyons, Ill.
GOODBARNE, A. S., Atlas Steels, Ltd., Welland, Ont., Can.
GOODMAN, G. H., S. G. Flagg & Co., Inc., Stowe, Pa.
GUTEKUNST, A. A., Auto-Lite Battery Corp., Syracuse, N. Y.
HAAS, S. J., Elec. Storage Battery Co., Phila., Pa.
HALBERT, S., Apex Alkali Prods. Co., Phila., Pa.
HOLZ, E. W., Downingtown Paper Co., Downingtown, Pa.
HOOPER, W. E., F. & W. Ursem Co., Cleveland, Ohio.
HOUSTON, C., Socony-Vacuum Oil Co., Hartford, Conn.
HURLEY, J. W., Ford Motor Co., Cleveland, Ohio.
KEISTER, R. E. III, Gen. Chem. Div. of Allied Chem., Claymont, Della.
KILMER, W. R., Sun Oil Co., Syracuse, N. Y.
KINNEAR, P. J., Standard Oil Co. (N.J.), N. Y., N. Y.
KLEIST, G. N., The Hodson Corp., Chgo., Ill.
KUNZE, A. W., Gemmer Mfg. Co., Detroit, Mich.

(Continued on page 165)

MINIMUM OIL REQUIREMENTS OF BALL BEARINGS*

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Dr. Wilcock received the degree of BS in Civil Engineering from Harvard Engineering School in 1934; in 1939 he earned a Doctor of Engineering Science degree from the University of Cincinnati, specializing in physics and physical chemistry. Following three years in the Sherwin-Williams Oil Research Laboratory developing solvent extraction processes, he joined the G.E. Research Laboratory where he worked on the chemistry and applications of silicone oils. In 1945 he undertook the organization of the G.E. Bearing & Lubricant Center at the Thomson Laboratory, and is now in charge of the Bearings & Chemistry Section, including the Center. He is a member of ASLE, ACS, ASTM, ASME and its Special Research Committee on Lubrication.

ABSTRACT: A study has been made of the running time of ball bearings operating with minute quantities of lubricating oil. The relations obtained indicate that medium size ball bearings can run for years on one drop of oil at moderate loads and speeds. Data are presented for various bearings, speeds, loads, and types of lubricants. Some correlation is obtained with life of greased ball bearings, and the results are also believed to be of utility in studying ball bearing construction, mist lubrication, and general ball bearing operation.

MINIMUM OIL REQUIREMENTS OF BALL BEARINGS: An evaluation of the minimum lubrication required by a ball bearing is essential to a basic knowledge of grease lubrication and oil mist lubrication. It is intimately related to the prediction of grease life. It furnishes a useful tool in studying the relation of ball bearing design to ease of lubrication. This paper reports some of the initial quantitative studies on the effects of load, speed, size and design of bearings on the amount of lubrication required.

Previous studies of ball bearing lubrication suggested the utility of this investigation. In a study of the mechanism of lubrication failure in high-speed ball bearings, the necessity of maintaining an oil film in the contact area between the balls and races was demonstrated[3]. This lubricating film minimizes the sliding friction in the ball-race contact area formed by elastic deformation of the balls and races when under load. Loss of this oil film leads in rapid succession to increased friction, excessive localized heating, loss of internal clearance, spalling or pitting of the races and balls, skidding balls, a broken ball separator, and a jammed bearing. The friction involved in the sliding of the ball retainer against the balls, and in some cases against the shoulders of the races, is also greatly relieved by a film of lubricant. The determination of the quantity of oil required to provide this minimal oil film so necessary for satisfactory operation has been an objective of this study.

The absence of sliding in the loaded contacts in a roller bearing results in much lower lubrication requirements. In such a bearing, lubricating oil is needed largely to minimize friction and pick-up from the rubbing of the rolls on the separator. When this separator pick-up is minimized by careful material selections, large high speed roller bearings have been run for periods up to several hours with only a thin film of oxidized petroleum oil[9].

A ball bearing grease is believed to function merely as a storehouse for oil[8]. In this capacity, a grease must bleed enough oil to the bearing to make up for losses by evaporation, atomization, creepage, and oxidation so that a sufficient quantity of oil is always present for the mechanical lubrication needs of the bearing. If the oil supply from the grease drops below this minimum requirement, the bearing soon fails.

In mist lubrication, a small amount of oil is fed to the bearings as atomized droplets in air. In recent studies, the critical minimum rate of oil application from such a system to ball bearings operating under several speed and load conditions has been reported[1].

MINIMUM OIL TESTER: The equipment used for these tests consisted essentially of a belt-driven jack-shaft for rotating bearings in a radially spring-loaded housing. A photograph of the assembled test unit is shown in Fig. 1. A constant speed oil feeder, built to deliver as little as one drop of oil per day by means of a gear reduction drive to a plunger on a hypodermic needle, was removed after a few initial tests because it was incapable of providing a slow enough delivery to approach the minimum oil requirements of a No. 306 test bearing.

Oil was applied to each test bearing as a benzene solution of from 1 to 10 per cent concentration. The solution was applied by an eye dropper to the bottom of the outer race and then spread over the working parts by slow rotation. The amount of solution applied was determined by difference weighing of the solution bottle, and the weight of oil was calculated from the weight and concentration of the solution. This calculated weight of oil was checked in several cases by direct weighing of the oiled bearing on a balance with 0.002 gm sensitivity.

The running life of a bearing was taken as the

*Sponsored by the ASLE Technical Committee on Bearing Lubrication and presented at the ASLE 7th Annual Meeting, Cleveland, April 9, 1952.

total operating time until the bearing became continuously noisy. The difference in time between the start of a continuous screeching noise and final seizure was generally only a few seconds at speeds of 1800 rpm or higher with No. 306 size ball bearings. At 900 rpm, however, several hours sometimes elapsed between the initial signs of distress and final failure. The nature of the higher speed bearing failure appeared similar to that reported by F. C. Jones and D. F. Wilcock[3], with the loss of an adequate film of lubricant between the balls and races causing high friction, ball skidding and cage breakage. At low speed, considerable friction oxidation was encountered at failure. The temperature rise on the outer bearing race during normal running was 5 C. or less in most cases.

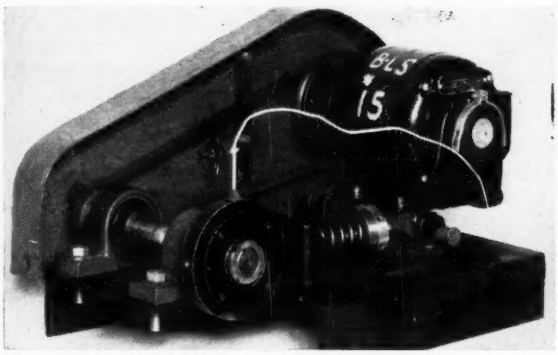

Fig. 1 Minimum Oil Tester.

EXPERIMENTAL RESULTS: For a given type of bearing operating under constant conditions of load and speed with one oil, the running time to failure was found to be a direct function of the quantity of lubricating oil. As an example of the relationships found, the data obtained for a number 306 size ABEC 1 bearing operating at a relatively light load is shown in Fig. 2. The least mean square data for various other oil-bearing combinations are indicated in Table 1. Correlation was generally quite good, with an average "coefficient of correlation"[6] of 0.92 for the equations given in Table I. This coefficient of correlation is a measure of the goodness of fit of the data to the least squares line. Its value ranges from zero for no correlation to unity for perfect correlation. When the quantity of MIL-O-6082 Grade 1065 aviation petroleum oil (470 Saybolt Second Viscosity at 100 F.) is plotted in Fig. 2 versus the running time to failure, two distinct exponential relationships are found to exist. The results in both cases can be correlated by the equation (1): $t=aw^n$. For quantities of oil less than approximately 0.35 milligrams this relationship becomes (2): $t=0.66\ w^{1.0}$, while for greater quantities of oil (3): $t=4.7\ w^{3.1}$.

The junction of the lines represented by Equations (2) and (3) at t_0, w_0 is believed to indicate the amount of oil necessary to cover the surface of the bearing adequately. For smaller quantities of oil than this, only short running life is possible while the oil is apparently dissipated by the friction energy introduced into the oil film by the operation of the bearing. For larger quantities of oil, the coverage of the bearing surface is sufficient to minimize friction; and the running time is more dependent upon other factors such as creep of the oil away from the operating parts of the bearing. For the data represented in Fig. 2, this weight of oil w_0 represents a layer approximately 2 microinches in thickness. This thickness is calculated by dividing the volume of oil weighing 0.35 milligrams by the approximately 15 square inches surface area of the ball grooves of the races, the balls, and the inside of the retainer pockets.

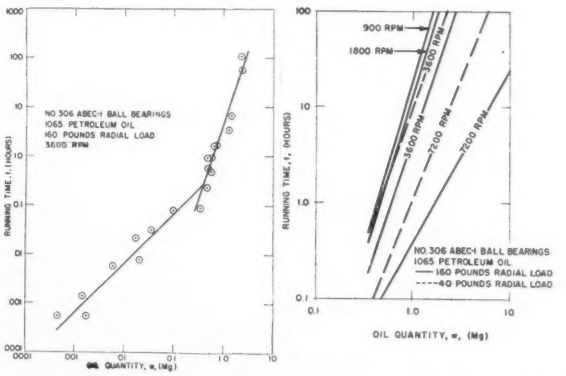

Fig. 2 (left) Relation of Running Life to Quantity of Grade 1065 Aviation Petroleum Oil.

Fig. 3 (right) Effect of Speed and Load on Minimum Oil Requirements.

For a given oil-bearing combination, a family of curves is obtained which represent the running life equations under various conditions of load and speed. Such a relationship for No. 306 bearings running at various loads and speeds with 1065 oil is represented by Fig. 3. This family of curves can be represented by modifying Equation (1) to the form (4):

$$\frac{t}{t_o}=\left(\frac{w}{w_o}\right)^n$$

where t_0 is the running time possible with the oil film represented to w_0. From Fig. 3 the running time t_0 on 0.35 milligrams of oil and n, the slope of the lines, are both seen to be a function of the load and speed. Both decrease with increasing speed and increasing load.

The least mean square relationships found for a number of other oil-bearing combinations are tabulated in Table 1 and are indicated graphically in Fig. 4. The data obtained with the low viscosity 1010 jet engine petroleum oil of 10 centistoke viscosity at 100 F. also indicate a value of w_0 of 0.35, the same as was found with the heavier 1065 petroleum oil. For a given load and speed, however, the value of the exponent n for 1010 oil operating in number 306 bearings was considerably lower than that obtained with the 1065 oil. With a methyl silicone oil of 40 centistokes viscosity at 100 F., the minimum oil weight w_0 was found to be 3.5 milligrams, or about 10 times as great as that with the two petroleum oils.

ANALYSIS OF THE LIFE EQUATION: The experiments described above have shown that for specific conditions the running life of ball bearings is an exponential function of the quantity of lubricating oil present. Obviously, there is an upper limit of w above which the exponential relations cannot be expected to hold, since the bearing cannot physically retain the oil; but because of the extremely long running times involved this limit

has not been found experimentally. Analysis of the parameters t_o, w_o, and n of the exponential function, Equation (4), leads to a generalized expression of great usefulness.

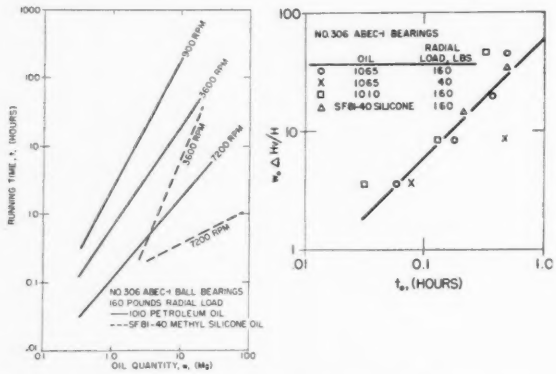

Fig. 4 (left) Life Curves for 1005 Jet Engine Oil and a Methyl Silicone Oil.

Fig. 5 (right) Relation of Running Time on Surface Covering Oil Film to Bearing Friction Loss and Heat of Evaporation of Oil.

The oil film thickness required for adequate coverage of the bearing parts is represented by the value of w_o. With the two petroleum oils of greatly different viscosity used in these tests, the thickness of this oil layer was approximately two microinches, which represents an adequate amount of oil to fill in the surface roughness in these bearings whose RMS finish was determined as approximately 4 microinches. For the silicone oil with its relatively poor lubricity properties for steel on steel, this minimum oil film was approximately ten times as great as that necessary with the petroleum oil. Although the value of w_o is doubtless dependent upon bearing finish, mechanical fit-up of the bearing, and oil lubricity, estimation of the value for different sizes of the same type of bearing can probably be made by adjusting w_o through the ratio of the surface areas of the different sizes.

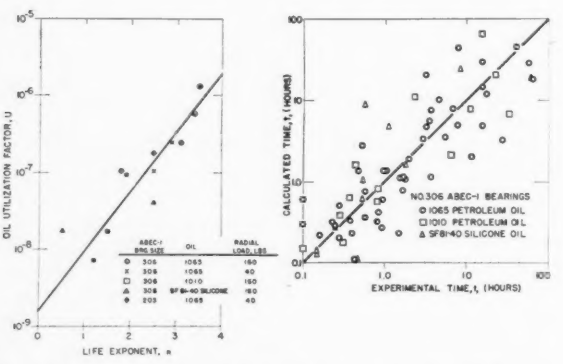

Fig. 6 (left) Relation of Life Exponent to Oil Utilization Factor.

Fig. 7 (right) Experimental Life in Individual Bearing Tests versus Life Calculated from Equation (9).

The running time t_o possible with the oil quantity w_o necessary for covering the operating parts of the bearing appears to be inversely proportional to the friction energy generated in the bearing. If a constant proportion of the friction energy dissipated by the bearing were utilized in evaporation of the oil film the following relationship would be expected to exist (5):

$$t_o = \frac{1.18 \times 10^{-7} w_o \Delta H_v}{kH}$$

where k represents the proportion of friction energy H being utilized in evaporating the oil quantity w_o. The numerical term 1.18×10^{-7} compensates for the different dimensional units involved. The values of the heats of evaporation, ΔH_v, were estimated from the literature to be 25 calories per gram for the silicone oil at 85 F.[7] and 65 calories per gram for the petroleum oils[2]. Friction energy dissipated in the bearings was estimated from the data of Muzzoli[5]. The resulting correlation for a number 306 bearing operating under various conditions of load and speed and with a number of lubricants is shown in Fig. 5 and may be expressed as (6):

$$t_o = \frac{w_o \Delta H_v}{60H} = \frac{1.18 \times 10^{-7} w_o \Delta H_v}{7 \times 10^{-6} H}$$

Although reasonably good correlation is obtained, the extremely small k indicates that only seven parts per million of the friction energy can be accounted for in the evaporation of the oil film. Further experimental work, particularly the direct measurement of the bearing friction appears desirable to establish this relation more firmly.

A number of dimensionless ratios, such as those proposed by Macks et al.[4] for analyzing the operating characteristics of roller bearings, were considered in an attempt to correlate the life coefficient n with the physical factors believed to be involved. Lubricant properties related to the loss of oil by creepage and evaporation were considered, such as oil viscosity, surface tension and vapor pressure. The bearing speed, bearing bore, and bearing load were introduced through a power loss term. Most of these factors could then be combined in a dimensionless "oil utilization factor" as defined in the following equation (7):

$$U = 1.02 \times 10^{-10} \frac{\mu \tau}{\rho H}$$

The numerical constant adjusts for the different dimensional units of μ, τ, ϱ, and H, so that U is a true dimensionless number. Although vapor pressure does not enter the relation as such, it is intimately associated with the viscosity of a given type of lubricant. For the oils used, the kinematic viscosity and surface tension data on Table II were adjusted to the test bearing temperature of approximately 85 F.

The relationship of the life exponent n to the oil utilization factor U is indicated in the semilog plot of Fig. 6 in which the data can be related approximately by the following equation (8):

$$n = 11.4 + 1.3 \log U$$
$$= 11.4 + 1.3 \log \left[1.02 \times 10^{-10} \frac{\mu \tau}{\rho H} \right]$$

This indicates that the life exponent increases for both increasing oil viscosity and increasing surface tension, both of which would reduce loss of oil by creepage away from working parts of the bearing. The life exponent decreases with increasing bearing speed and increasing load which result in higher power loss. Here again power loss was estimated from the results of Muzzoli[5].

The life exponent n appears to be intimately

related to the mechanism by which oil is lost from a bearing. A fine cloud of mist appearing about the bearing when using silicone oil at high speeds suggested that atomization was responsible for most of the loss when the exponent dropped much below a value of 1.0. If vaporization from the ball track were the only factor involved, the running time would be expected to be proportional to the amount of oil (n=1), since the friction energy is supplied to the oil film at a uniform rate. The low exponent of approximately 1.2 with the rather volatile 1010 oil suggests that vaporization may have been playing an important role. Although vapor pressure is not included as such in the oil utilization factor, volatility is accounted for indirectly through the viscosity term. The higher exponents extending up to a value of 3.5 with the more viscous 1065 oil on bearings operating at low speed are probably associated with oil creep. An attempt to apply an oil creep barrier along the edges of the raceways and on the outer surface of the retainers cut by a factor of about 10 the oil required for a given time of operation of 306 bearings at 3600 RPM. It is hoped that future work will establish more definitely the mechanism for this oil loss from ball bearings.

TABLE I

Brg. Mfg.	Oil	Speed, RPM	Hours to Failure, $t = aw^n$ a	n
160 Pounds Radial Load				
A	1065	900	19	3.5
	1065	1800	13	3.4
	1065	3600	4.7	3.1
	1065	7200	0.39	1.8
A[a]	1065	3600	15	2.4
B[b]	1065	3600	27	3.1
C	1065	3600	3.7	3.0.
D	1065	3600	30	2.2
A	1010	900	2.4	1.9
		3600	0.63	1.5
		7200	0.11	1.2
A	Silicone	3600	0.020	2.5
		7200	0.11	0.51
40 Pounds Radial Load				
A	1065	3600	10	2.9
		7200	1.1	2.5
C[c]	1065	7200	230	2.5

TABLE II

Oil	MIL-O-6082 Grade 1065 (Petroleum)	MIL-O-6081 Grade 1010 (Petroleum)	SF 81-40 Methyl Silicone
Kinematic Viscosity, cs.			
At 100 F.	103.5	10.14	40.2
At 210 F.	11.26	2.51	17.1
Viscosity Index	103	75	172
Surface Tension, Dynes/Cm. at 25 C.	33.2	31.2	21.5
Gravity, °API	30.2	31.3	14.3
Flash Point, C.O.C., °F.	455	295	595
Pour Point, °F.	-10	-80	+120

Table I (top) Relationship of Running Life of Ball Bearing to Amount of Lubricating Oil; No. 306 ABEC 1 ball bearings, except as noted. a: ABEC 5 Precision No. 306 bearings, b: ABEC 1-3 No. 306 bearings, c: ABEC 1 No. 203 bearings.

Table II (bottom) Properties of Test Oils.

A generalized life equation which expresses essentially all of the data obtained in these experiments with ABEC 1 bearings may be obtained by using all of the above relationships. Substituting Equations (6) and (8) for t_0 and n in the general Equation (4) gives the following expression (9):

$$t = \frac{w_0 \Delta H_v}{60H} \left(\frac{w}{w_0}\right)^{11.4+1.3 \log U}$$

The degree of correlation obtained for the experimental data through the use of Equation (9) is indicated in Fig. 7 where the calculated values of running time t are compared with the actual experimental values. The bearings used were all No. 306 bearings from a single manufacturer, eliminating any change in w_0 because of surface finish or bearing design. Although a few of the calculated values of running time differ from the experimental times by a factor of as much as ten in this plot, the oil quantities involved vary several hundred fold, the running times several thousand fold, the speed eight fold, and the load four fold. Considerable differences are also involved in the physical properties of the three lubricants used. A high correlation coefficient of 0.92 for the data shown in Fig. 7 gives a strong indication of the generality of Equation (9) for expressing the experimental data. Similar equations could be determined for other bearings by a few experiments to establish appropriate values of w_0 and the numerical constants.

PRACTICAL APPLICATIONS OF MINIMUM OIL STUDIES: An analysis of the operation of ball bearings with very small quantities of oil is expected to be most useful in considering the fundamentals of grease lubrication. Thus, the successful operation of greased bearings customarily depends upon the minute quantities of oil available from the grease. The small, but positive, lubrication requirements of ball bearings found in this study indicates that the grease should function to release very gradually and at as uniform a rate as possible the small necessary amounts of oil into the working parts of the bearing.

Correlation between the minimum oil results of Table I and ball bearing grease life tests is indicated in the following comparison of results with conventional soda-base grease life at 100 C. in open No. 306 size bearings from manufacturer A. All these tests were made with 160 pounds radial load at 3600 rpm.

Bearings	Running Time on One Milligram of Oil Hrs.	Geom. Mean Life in Grease Test Hrs.
Conventional ABEC-1	4.7	2000
Precision ABEC-5	14.5	4000

Thus, the life available in greased ball bearings depends on the oil requirements of the bearing as well as on the grease characteristics. Work is underway to try to develop a more quantitative expression for the relation of ball bearing grease life to minimum oil requirements.

Information on minimum oil requirements is also useful in considering fluids for grease formulations. Differentiating Equation (4) gives the rate of oil consumption as follows (10):

$$\frac{dw}{dt} = \frac{w_0^n}{t_0 n w^{n-1}}$$

When $n < 1$ the rate of oil utilization becomes greater the more lubricating oil there is present on the bearing, indicating the inability of the system to be satisfied with additional lubricant. With the silicone oils tested above, and with a methyl phenyl silicone oil, this value of n=1 was reached at a DN speed factor of between 108,000 and 216,000. These bracket the speed factor of 150,000 frequently given as the upper limit to be used for silicone greased bearings. Thus, minimum oil studies provide a quick means of evaluating the suitability of fluids for grease compositions intended for extreme operating conditions.

High viscosity and high surface tension are shown by the correlation of Fig. 5 to be desirable properties of an oil for long life grease formula-

(Continued on page 156)

THE LUBRICATION CHARACTERISTICS OF SYNTHETIC LUBRICANTS AT HIGH SLIDING VELOCITIES *

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Mr. Swikert attended Kalamazoo College and Tri-State College, receiving his BS degree in Mechanical Engineering in 1943. After a brief period doing mechanical design work for Consolidated-Vultee at Fort Worth, Texas, he joined the research staff at NACA Lewis Flight Prop. Lab. where he has been continuously engaged in applied and fundamental lubrication and wear research.

Mr. Bisson attended the Universities of Vermont and Florida, receiving his BS degree in Mechanical Engineering from the latter in 1938. He joined NACA at Langley Field in 1939; in 1943 he was transferred to NACA Lewis Flight Prop. Lab. as Head of the Piston Ring & Cylinder Barrel Research Section, in 1945 being named Head of the Lubrication, Friction & Wear Research Section. He is at present the NACA representative on the Co-operative Research Council's group on Aircraft Gas-Turbine Engine Bearings & Their Lubricants, and a member of the NACA Sub-committee on Lubrication & Wear.

ABSTRACT: New types of lubricants are necessary to meet the stringent requirements of future aircraft turbine engines. Since many of the rubbing surfaces in these engines operate under conditions of boundary lubrication, the friction and surface-failure properties of the lubricant are of extreme importance. In consequence, the boundary lubrication characteristics of several classes of synthetic lubricants were studied over a wide range of sliding velocities at the NACA laboratories.

Most uninhibited synthetics, including diesters, polyethers, a silicate ester and phosphonate esters are more effective boundary lubricants at high sliding velocities than petroleum oils of comparable viscosity at 100 F. The breakdown of effective lubrication takes place at a much higher sliding velocity with these synthetic fluids than with the petroleum oils. A silicone-diester blend proved to be a much more effective boundary lubricant at high sliding velocities than either the silicone or the diester. A diester failed to lubricate non-reactive surfaces which indicates that the lubrication mechanism for diesters may involve chemical reaction with the lubricated surfaces.

INTRODUCTION: It is currently appreciated[1,2,3,4] that new types of lubricants must be found to replace current petroleum lubricants for the turbine-type aircraft engines of the immediate future. The present lubricants (specification MIL-0-6081a, grades 1010 and 1005), are not completely satisfactory because they are either too viscous for adequate pumpability at low temperatures or because they have marginal lubricating ability and excessive volatility at present bearing operating temperatures. In the aircraft turbine engine the lubricant requirements are further complicated by high "soak back" temperatures, approaching 500 F. at present.

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New engines will have operational requirements of higher bearing operating temperatures and lower starting temperatures. Since there is no evidence that petroleum can wholly satisfy these requirements, other lubricants such as synthetic fluids have come into the picture. Military specification MIL-L-7808 covers such synthetic lubricants.

A number of synthetic fluids have either been considered or merit consideration as turbine lubricants on the basis of their viscometric and thermal stability properties. Unfortunately boundary lubrication and friction data on these fluids are limited. For example, the data on friction coefficients with some types of synthetic fluids which are included in Refs. 5 & 6 are very limited. In consequence, boundary lubrication studies were made at the NACA Lewis laboratory for steel-on-steel lubricated with a number of synthetic fluids of various classes.

Experiments were conducted with a kinetic friction apparatus consisting of a steel ball sliding on a lubricated, flat, steel disc. Data were obtained on very thin films of synthetic fluids at sliding velocities from 75 to 12,000 feet per minute and with a load of 269 grams (initial Hertz surface stress, 126,000 lb/sq in.). The fluids studied included di(2-ethylhexyl) adipate, di(2-ethylhexyl) sebacate, diisooctyl adipate, diethylene glycol benzoate 2-ethelhexoate, tripropylene glycol *n* butyl ether, water soluble polyalkylene glycol, water-insoluble polyalkylene glycol, polydimethyl siloxane, a silicone-diester blend, an alkylsilicate ester, two phosphonate esters, and a halocarbon.

The material on which this paper is based, is covered in more detail in Ref. 7.

EXPERIMENTAL FLUIDS: The properties of the synthetic fluids used as lubricants in these experiments are listed in Table 1. Commercial fluids were used without special treatment inasmuch as previous unpublished data obtained at the NACA Lewis laboratory had indicated that percolation of diesters through silica, alumina, and Fuller's earth had no measurable effect on frictional properties under extreme boundary lubrication conditions. No marked effect of percolation on friction was found in the research of Ref. 8 where data were obtained with synthetics such as diesters and polyglycol ethers.

The diesters are the class of synthetic fluids most widely accepted as aircraft lubricants and have been considered favorably for some time by, among others, the Naval Research Laboratory and the Petroleum Refining Laboratory, Pennsylvania State College. Military specification MIL-L-7808 has a reference lubricant compounded using a

diester as the base stock. Diesters have very good viscometric properties and effective oxidation inhibitors have been developed for specific fluids.

The polyethers were among the first commercially available synthetic lubricants. They have viscometric properties superior to those of the petroleum oils. Several polyether fluids have desirable thermal stability properties in that they do not generally form solid decomposition products. Theoretically, the fluids crack and the resulting fractions volatilize without leaving any residue.

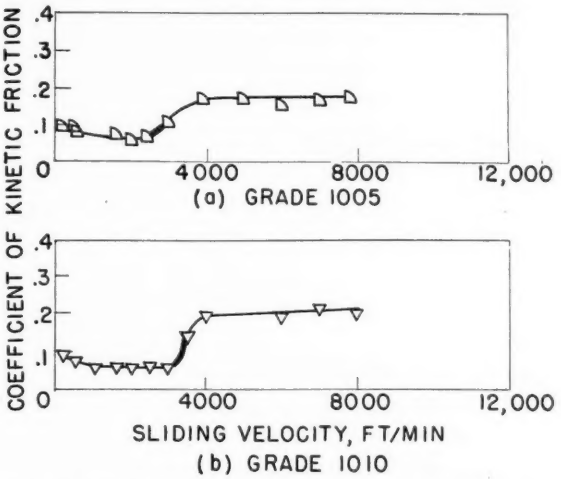

Fig. 1 Effect of sliding velocity on friction of steel surfaces lubricated with specification MIL-O-6081 petroleum oils. Load, 269 grams (initial Hertz surface stress 126,000 lb/sq in.). Heavy line shows range of incipient surface failure (range of effective boundary lubrication is shown at lower sliding velocities; range of mass surface failure is shown at higher sliding velocities).

Silicones have the best viscometric properties of any known liquids. The silicones, however, have two limitations: (1) inadequate oxidation resistance or thermal stability and (2) poor lubricating effectiveness (particularly for steel surfaces).

The silicate esters have very good viscometric properties and, when properly inhibited, can have good thermal stability as well as hydrolytic stability. These properties make the silicate esters a very promising class of fluids for use as lubricants. One of the products of decomposition of the silicate esters, however, is silica which under certain conditions could be abrasive.

The phosphonate esters have fairly good viscometric properties. There has been speculation about probable toxicity and corrosiveness at elevated temperatures; these properties have not yet been adequately studied although some data are available on corrosion.

The fluorocarbons are high-density organic fluorine compounds that are most notable for chemical stability. Their viscometric properties are less desirable than the other synthetic and petroleum fluids.

The petroleum lubricants (Table I) are included for purposes of comparison with the synthetic fluids.

APPARATUS & PROCEDURE: Friction apparatus — The friction apparatus used for these experiments is that described in Ref. 5. The apparatus consists primarily of two elements, an elastically restrained spherical rider (¼ in. balls of SAE 1095 steel hardened to Rockwell C-60) and a rotating disc (normalized SAE 1020 steel, hardness Rockwell A-50). Friction force between the rider and the disc is measured by four strain gages mounted on a copper-beryllium dynamometer ring. The friction force readings F are recorded using a motion-picture camera timed to operate for the 3 seconds covering the duration of each friction run. The coefficient of kinetic friction u_k is the ratio of the measured friction force F to the applied normal load P.

The rider traverses a spiral path on the rotating disc so that portions of the wear track do not overlap. The disc and rider are enclosed, which permits the operating atmosphere of dried air to be slightly pressurized.

Preparation of friction specimens — The disc specimens are prepared according to the detailed procedure reported in Ref. 9. The procedure includes finish lapping of the surfaces, then cleaning (consisting of degreasing, scrubbing with moist levigated alumina powder, testing for cleanness by the ability of water to wet the surface, rinsing with redistilled 95-percent ethyl alcohol), and drying in the friction apparatus with an atmosphere of dried, filtered air.

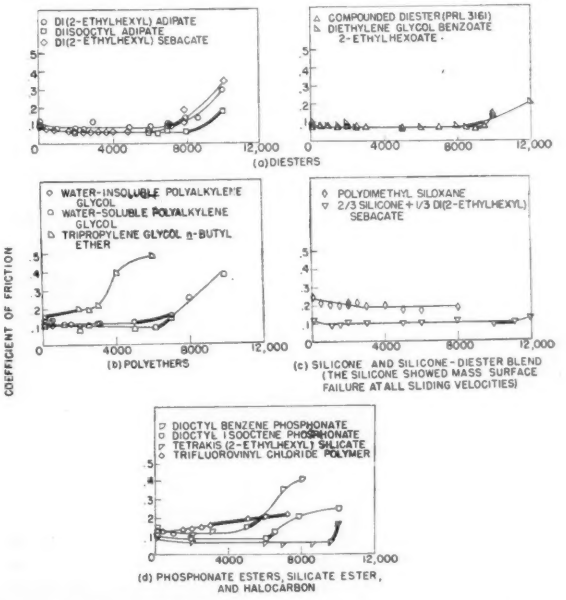

Fig. 2 Effect of sliding velocity on friction of steel surfaces boundary lubricated with several synthetic fluids. Load 269 grams (initial Hertz surface stress 126,000 lb/sq in.). Heavy line shows range of incipient surface failure (range of effective boundary lubrication is shown at lower sliding velocities; range of mass surface failure is shown at higher sliding velocities).

Experimental procedure — During the experiments, the disc was rotated at a predetermined speed, and the rider was lowered onto the disc and caused to traverse a spiral track on the disc. Duration of the friction run was 3 seconds. Virgin surfaces on both the disc and rider were used in each run (each run is shown as an individual data point on the friction curves).

The lubricating fluids were applied to the disc surface in drops from a clean platinum dipper and

were allowed to wet the surface completely. The film was then rubbed with lens tissue which produced an extremely thin film on the disk[10].

The friction data for each lubricant studied were readily reproducible; in all but isolated cases, the maximum deviation in the coefficient-of-friction data for a given experimental condition was ±0.02 and, in general, was considerably less.

RESULTS & DISCUSSION: The most significant results to be discussed in regard to the data presented herein are those showing the effect of sliding velocity on surface-failure and friction coefficients obtained with the various fluids. Failure points were determined by: (a) inspection of surface appearance for welding or metal transfer, (b) wear rates, and (c) friction trends. Three conditions of lubrication were observed: (1) no failure (that is, effective lubrication), (2) incipient surface failure, and (3) mass surface failure. In all the data curves which follow, the incipient failure range is indicated by a heavy line. When effective boundary lubrication was obtained, the coefficient of friction was essentially independent of load. Surface failure results for all lubricants are summarized in Table II.

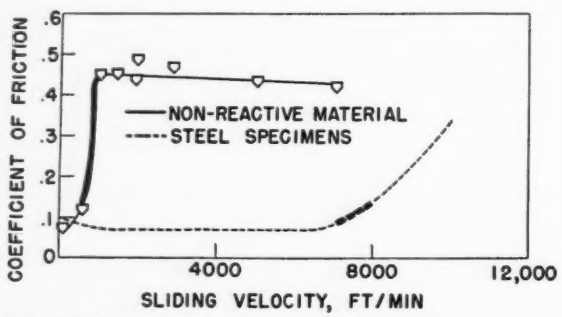

Fig. 3 Effect of slider materials on lubrication by a typical diester lubricant, di(2-ethylhexyl) sebacate. Load 269 grams. Heavy line shows range of incipient surface failure (range of effective boundary lubrication is shown at lower sliding velocities; range of mass surface failure is shown at higher sliding velocities).

Petroleums — The effect of sliding velocity on the lubrication of steel surfaces by conventional petroleum lubricants is discussed in Ref. 5. The data for petroleum oils (MIL-O-6081a, grades 1010 and 1005) presented in Fig. 1 are taken from Ref. 5, and are included herein for comparison with the synthetic fluids to be discussed later. In the region of effective boundary lubrication, data of Ref. 5 and unpublished studies show that viscosity had no effect on friction and surface failure. It should be noted (Fig. 1) that both grade 1010 and grade 1005 produced friction coefficients from 0.06 to 0.10 in the range of sliding velocities where they were effective lubricants. Incipient surface failure was observed at 3000 feet per minute with grade 1010 and at 2400 feet per minute with grade 1005.

Failure is believed to be a function of the rate of heat energy released in sliding. At high sliding velocities, the increased amount of heat generated causes physical desorption of, or lubricant decomposition in, the boundary film, allowing metallic contact. For lubricants within the same class, the sliding velocity at which failure takes place (critical velocity) is believed to be a function of the high temperature stability of the particular lubricant.

Diesters — In the region of effective boundary lubrication, the friction coefficients obtained with the several diester-type fluids (Fig. 2(a)) are in the same range as those obtained for the petroleum lubricant. The presence of an anti-wear additive (5 percent tricresyl phosphate) in the compounded diester (PRL 3161) has no beneficial effect on friction coefficient in this region of effective lubrication. All the diesters studied provided effective lubrication at sliding velocities at least twice as high as the petroleum oil (grade 1010, Fig 1) which has similar room temperature viscosity. Ref. 6 (p. 860) points out that ". . . there is no significant difference in the friction and wear reducing properties of these esters and the mineral oils described." While this result is true under the experimental conditions of Ref. 6, it is obvious from the experimental results reported herein that there is a considerable difference between the diesters and the petroleum oils in their ability to provide effective lubrication at high sliding velocities.

Fluid	Viscosity at °F (cs)				A.S.T.M. pour point (°F)	C.O.C. flash point (°F)	C.O.C. fire point (°F)
	-65	-40	100	210			
Diesters							
Di(2-ethylhexyl) adipate[a]	6000	877	8.12	2.34	-94	395	418
Diisooctyl adipate[a]	6962	-----	10.13	2.63	-103	408	418
Di(2-ethylhexyl) sebacate[a]	8297	-----	12.78	3.32	<-70	440	472
Di(2-ethylhexyl) sebacate plus additives[b,c]	16,000	2700	20.8	5.3	<-75	450	475
Diethylene glycol benzoate 2-ethylhexoate[b]	g	-----	10.9	2.5	-70	415	425
Polyethers							
Tripropylene glycol n-butyl ether[a]	4657	-----	5.07	1.42	-105	288	395
Polyalkylene glycol (water soluble)[a]	12,503	-----	9.28	2.43	-83	220	230
Polyalkylene glycol (water insoluble)[a]	4587	-----	7.87	2.35	<-103	280	300
Silicones							
Polydimethyl siloxane[a]	668	-----	39.75	15.3	<-103	520	585
Silicone-diester blend							
Polydimethyl siloxane plus one-third di(2-ethylhexyl) sebacate	------	205	15.5	5.75	<-75	375	415
Silicate ester							
Tetrakis(2-ethylhexyl) silicate[b,f]	1400	260	6.8	2.4	<-100	395	450
Phosphonate esters							
Dioctylbenzene phosphonate[a]	------	[d]8359	11.38	2.64	-87	----	----
Dioctylisooctene phosphonate[a]	------	[d]9003	12.22	2.77	-90	----	----
Halocarbon							
Trifluorovinyl chloride, polymer[a]	6524	-----	4.13	1.13	-105	none	none
Petroleum[e]							
MIL-O-6081a(grade 1010)	40,000	-----	9.95	2.47	<-70	300	----
MIL-O-6081a(grade 1005)	2000	315	5.03	1.64	<-76	220	----

Table 1 — Properties of experimental fluids. Key: [a]Measured values. [b]Manufacturer's data. [c]Additives consist of 0.5 percent phenothiazine, approximately 4 percent viscosity index improver, and 5 percent tricresyl phosphate. [d]At −50 F. [e]For comparison only. [f]Includes oxidation inhibitor. [g]Above pumpability limit.

While viscosity is a convenient standard for comparing the "thick-film" lubricating effectiveness of various lubricants, no fundamental effect of viscosity in the region of effective boundary lubrication should be anticipated. This lack of effect has been shown in unpublished studies and is also confirmed by the data on diesters of variable viscosity (see Table I and Fig. 2(a)). Chemical structure may be a basis for comparison of diesters. The two diesters of Fig. 2(a), which show incipient surface failure in identical sliding velocity ranges, had the same alcohol group in their structure. The diester which provided more effective lubrication had the same acid group as one of the other diesters that was made with a different alcohol.

No explanation is available at this time as to the reason for the extended effective boundary lubrication region of the compound diester (PRL 3161). This lubricant, however, contains tricresyl phosphate as well as an oxidation inhibitor, a VI improver and an anti-foam agent. The individual effects of these additives are being analyzed at the present time and results will be reported in a future paper.

For a complete study of lubrication effectiveness it was necessary to take photomicrographs of the wear areas. With all diesters, in the range of velocities where effective lubrication was obtained, the wear-areas of the rider (ball) specimens showed both the absence of welding and the presence of a tan surface film. When incipient failure of the lubricated surfaces occurred, the tan film became mottled, with small areas of uncoated and slightly disturbed metal appearing. The observed surface stain or film may be a reaction product of the diester and the steel surface as suggested in Ref. 11. This possibility will be discussed in the section Practical Considerations.

Progressive failure occurred at higher sliding velocities and showed a marked increase in size of the wear spot as mass failure occurs. The wear areas in these studies were typical of those observed with other lubricants in the various stages of lubrication effectiveness and serve to illustrate what is meant when effective lubrication, incipient surface failure, or mass surface failure are described.

Polyethers — Although they are effective lubricants, the polyalkylene glycols do not produce quite as low values of coefficient of friction (Fig. 2(b)) as were obtained with either the petroleum lubricants (Fig. 1) or the diesters (Fig. 2(a)). The polyalkylene glycol fluids provided effective boundary lubrication at sliding velocities substantially higher than those at which the petroleum oils were effective but they were not effective at sliding velocities as high as were the diesters. Incipient surface failure occured at around 5000 feet per minute for the water-insoluble and at 6000 feet per minute for the water-soluble polyalkylene glycols.

The tripropylene glycol *n*-butyl ether is marketed as a heat-transfer fluid and is not commercially represented as a lubricant. This material was studied in order to determine whether or not the lubricating properties observed for the fluids of Fig. 2(b) were common to other polyethers. With the heat-transfer fluid, friction was high and surface failure was observed over the entire range of sliding velocities. This result would indicate that good lubricating ability is not common to all polyethers.

Silicones & Silicone-Diester Blend — The effect of sliding velocity on lubrication effectiveness for a silicone (polydimethyl siloxane) and for a silicone-diester blend is shown in Fig. 2(c). As indicated, the polydimethyl siloxane produced mass surface failure at all conditions of the experiment, and the friction coefficients were considerably higher than with most other lubricants.

The lubricating properties of silicones can be markedly improved by blending them with 30 to 50 percent by volume of solvent[12]. A blend of 1/3 diester and 2/3 silicone was suggested therein as a probable practical lubricant having both good lubrication properties and good viscometric properties. The data of reference 12 were at low sliding velocities (120 ft/min) and data at high sliding velocities are not available. The data of Fig. 2(c) were therefore obtained at high sliding velocities with a blend of 1/3 di-2 ethylhexyl sebacate in a silicone fluid (one-half 50 centistoke (at 25 C.) silicone and one-half 10 centistoke (at 25 C.) silicone). At 100 F., viscosity of the silicone-diester blend was appreciably less than that of the polydimethyl siloxane (Table I). This blend was a very effective lubricant as shown in Fig. 2(c). Friction coefficients were in a range that are common to effective boundary lubrication and there was no excessive wear or evidence of surface failure until the sliding velocity exceeded 10,000 feet per minute. The degree of incipient surface failure was greater at sliding velocities of 11,000 and 12,000 feet per minute but extreme mass failure was not observed.

Fluid	Velocity for incipient surface failure (fpm)
Diesters	
Di(2-ethylhexyl) adipate	7,000
Diisooctyl adipate	8,000
Di(2-ethylhexyl) sebacate	7,200
Di(2-ethylhexyl) sebacate plus additives	9,000
Diethylene glycol benzoate 2-ethylhexoate	8,500
Polyethers	
Tripropylene glycol n-butyl ether	75
Polyalkylene glycol (water soluble)	6,000
Polyalkylene glycol (water insoluble)	5,000
Silicones	
Polydimethyl siloxane	(a)
Silicone-diester blend	
Polydimethyl siloxane plus one-third di(2-ethylhexyl) sebacate	10,000
Silicate ester	
Tetrakis(2-ethylhexyl) silicate	9,500
Phosphonate esters	
Dioctylbenzene phosphonate	5,000
Dioctylisooctene phosphonate	6,000
Halocarbon	
Trifluorovinyl chloride polymer	3,000
Petroleum	
MIL-O-6081a(grade 1010)	3,000
MIL-O-6081a(grade 1005)	2,400

Table II — Sliding velocity for incipient surface failure with various synthetic lubricants (Incipient surface failure point based on: surface appearance, wear rates and friction trend.). Specimens, steel on steel; load, 269 grams; initial Hertz surface stress, 126,000 lb/sq in. Key: [a]Showed mass surface failure at all sliding velocities.

Silicate & Phosphonate Esters — The alkyl silicate ester (tetrakis (2-ethylhexyl) silicate) is an effective boundary lubricant at sliding velocities to 9500 feet per minute (Fig. 2(d)). Mass surface failure occurred at 10,000 feet per minute. The friction coefficients obtained with the silicate ester under conditions of effective boundary lubrication were as low as those experienced with any of the fluids studied.

Lubrication data for the two phosphonate esters are also given in Fig. 2(d). The dioctyl benzene phosphonate provided effective boundary lubrication at sliding velocities up to 5000 feet per minute, as which incipient surface failure was observed. The dioctyl isooctene phosphonate was a slightly better boundary lubricant than the other phosphonate; incipient surface failure occurred at 6000 feet per minute and mass failure occurred at 6500 feet per minute.

Halocarbons — Data were also obtained for

a halocarbon (trifluorovinyl chloride polymer) and the results indicate (Fig. 2(d)) that friction increases as the sliding velocities increase. Visual studies of the surface did not show any indication of incipient surface failure until a sliding velocity of 3000 feet per minute was obtained. Mass failure apparently occurred to the surface at 7000 feet per minute, although failure was not as drastic as that experienced with other types of lubricants. The unusual behavior of this fluid may be accounted for on the basis of decomposition of the lubricant to the form compounds having "extreme pressure" characteristics. The decomposition might have produced a chlorine compound which acted as the "extreme pressure" agent.

Practical Considerations — The requirements of future aircraft turbine engines with respect to viscometric and thermal stability properties appear rather severe at the present time. Some relaxation in the requirements based on design changes and a better understanding of the lubrication phenomenon in aircraft turbine engines possibly could be made. An example of a design change would be the use of a pumping system to handle more viscous fluids at low temperatures. Also, high-temperature minimum viscosity requirements might be relaxed for specific types of engines. As discussed in more detail in Ref. 7, relaxation of high-temperature minimum viscosity requirements might be possible for present turbojet engines. In the turbojet engine, operating in the region of boundary lubrication, it has generally proven advantageous, from a lubrication standpoint under critical conditions of temperature, load or sliding velocity, to go to higher viscosities.

Reduction gearing of turbine-propeller engines, where high loading is encountered, represents a different problem. In this case, high viscosity is desirable at operating temperature because gear lubrication has an important hydrodynamic component[13]. The good viscometric properties of silicone-diester blends might be employed to satisfy the very stringent high-temperature-viscosity requirement necessary to enable the hydrodynamic component to be fully utilized in obtaining increased load capacity of gearing. The physical properties and lubricating abilities of the silicone diester blends have not been fully evaluated; however, these blends show considerable promise.

The silicate ester (as well as the silicone-diester blend) is a very good lubricant for high sliding velocities and has exceptional viscometric properties (Table I). Because of these good viscometric properties, more viscous silicate esters could probably be used for gear lubrication. Hydrolytic instability of silicate esters is a very important problem that could, however, be a limiting factor in their widespread use.

The majority of synthetic lubricants being considered for use in aircraft turbines are esters of various types. In the data presented herein all the ester-type fluids (diesters, silicate ester, and phosphonate esters) had good lubrication properties. In the course of future development of the use of these fluids, it is important to have some basic understanding as to why esters lubricate. One reasonable concept of the mechanism of lubrication for esters, as described in Refs. 6 & 11, indicates that hydrolysis of esters would lead to the formation of a very small amount of fatty acid which, when adsorbed, could attack the metal to form the corresponding soap film. Thus, lubrication would be provided by a chemisorbed soap film resulting from lubricant decomposition.

In order to check the validity of the suggested mechanism, an experiment was conducted with non-reactive friction specimens lubricated with a typical diester. A synthetic sapphire (Al_2O_3) ball was used, sliding on a Vycor glass disc lubricated with a rubbed film of di(2-ethylhexyl) sebacate. The results of this run (Fig. 3) indicate that chemical reaction may be important in lubrication by ester-type fluids. With the non-reactive specimens, the diester did not provide effective lubrication except at the minimum sliding velocity of 75 feet per minute, and the type of surface failure progressed rapidly to a severe scoring. If the mechanism of lubrication is one of hydrolysis and subsequent metal attack to form the soap film, the type of metal to be lubricated must be considered. Esters may not lubricate the noble-type metals that are not attacked by fatty acids; thus, silver plated parts in rubbing contact might not be adequately lubricated.

Qualitative observation of the performance of polyether lubricants indicates that available oxygen (from moisture or possible from decomposition of the lubricant) and the formation of oxide films on surfaces have considerable effect on lubrication. With several polyether fluids, erratic performance was observed during screening tests with a SAE lubricant tester modified to have the specimens operating in pure sliding, with no hydrodynamic lubrication possible. When particularly good results were obtained, the specimens had formed surface films that were believed to be oxides. Also, better results were obtained with the water-soluble series than the water-insoluble series having, otherwise, essentially the same properties.

SUMMARY OF RESULTS: Studies were made of the lubricating effectiveness of various classes of uninhibited synthetic fluids in boundary lubrication of steel surfaces at high sliding velocities. A simplified summary of the results, showing the sliding velocity at which incipient surface failure is obtained for the various synthetic lubricants, is shown in Table II. From these results and the preceding discussions, the following observations can be made: (1) Sliding-friction data and surface-failure properties show that a number of synthetics including diesters, polyethers, a silicate ester, and phosphonate esters are more effective boundary lubricants at high sliding velocities than petroleum oils of comparable viscosity at 100 F. The breakdown of effective lubrication takes place at a much higher sliding velocity with these synthetics than with the petroleum oils. (2) A silicone-diester blend proved to be a much more effective boundary lubricant at high sliding velocities than either the silicone or the diester. (3) A diester failed to lubricate non-reactive surfaces which indicates that the lubrication mechanism for diesters may involve chemical reaction with the lubricated surfaces.

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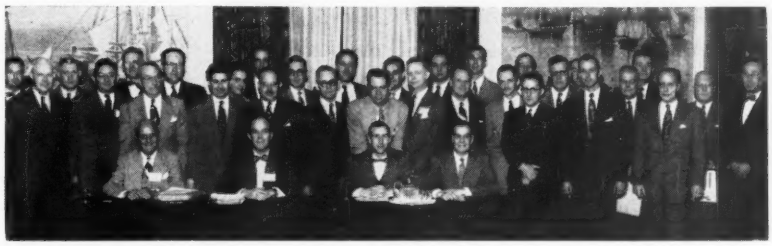
[5]R. L. Johnson, D. Godfrey & E. E. Bisson: Friction of Surface Films Formed by Decomposition of Common Lubricants of Several Types. NACA TN 2076, 1950.
[6]J. E. Brophy & W. A. Zisman: Surface Chemical Phenomena in Lubrication. Annals of New York Academy of Sci., Vol. 53, Art. 4, June 27, 1951.
[7]R. L. Johnson, M. A. Swikert & E. E. Bisson: Effective Lubrication Range for Steel Surfaces Boundary Lubricated at High Sliding Velocities by Various Classes of Synthetic Fluids. NACA TN 2846, 1952.
[8]W. C. Clinton: A Study of the Four-Ball Wear Machine. Rep. 3709, Naval Res. Lab., (Washington, D.C.), Sept. 1950.
[9]R. L. Johnson, M. A. Swikert & E. E. Bisson: Friction at High Sliding Velocities. NACA TN 1442, 1947.
[10]L. H. Germer & K. H. Storks: Rubbed Films of Barium Stearate and Stearic Acid. Phys. Rev., Vol. 55, No. 7, 2nd ser., pp. 648-654, April 1, 1939.
[11]F. P. Bowden & D. Tabor: The Friction and Lubrication of Solids. Clarendon Press (Oxford), p. 215, 1950.
[12]S. F. Murray & R. L. Johnson: Effect of Solvents in Improving Boundary Lubrication of Steel by Silicones. NACA TN 2788, 1952.
[13]H. Blok: Gear Wear as Related to Viscosity of Oil. Mechanical Wear, pub. by Am. Soc. Metals, pp. 199-227, 1950.

(Editor's Note: A discussion of this paper appears on page 170.)

Section News



Annual Section Officers Meeting, ASLE 8th Annual Meeting & Exhibit, Hotel Statler, Boston, April 12, 1953.

CHICAGO: March meeting—J. L. Duchene, National Bearing Div. of American Brake Shoe Co., presented a paper entitled Applications For Bronze Bearing Material, and R. L. Berry, American Brake Blok Div. of American Brake Shoe Co., addressed the section on Applications For Composition Bearing Material. (Submitted by A. B. Two, Sec'y-Treasurer.)

CLEVELAND: February meeting—A "Stump the Experts" quiz program with W. P. Youngclaus, Jr., ASLE Administrative Secretary, as Quizmaster; J. L. Finkelmann, Warren Refining & Chemical Co., J. E. Sonnefield, Aluminum Co. of America, and A. Nicol, Ferro Corp., as Judges; and as Panel Members: C. L. Seelbach, Shell Oil Corp.; R. H. Brandgard, Cadillac Tank Plant; K. W. Zintz, Hoover Co.; R. J. Shager, Cleveland Graphite Bronze Co.; G. F. Fenker, Pennsylvania Refining Co.; and W. J. Rodenberger, Republic Steel Corp. (Submitted by R. H. Josephson, Sec'y.)

DAYTON: March meeting—Joint meeting with the Dayton Section of ASME, with P. W. Dunlap, S.K.F. Industries, speaking on Factors Concerning Service Life Of Ball Bearings, in which ball and roller bearing designs and types, their lubrication, installation, removal, cleaning, and handling were discussed, and the service troubles resulting from over lubrication and improper cleaning and handling were stressed. Mr. Youngclaus presented the section with their official ASLE Charter. (Submitted by A. H. Turner, Vice-Chairman.)

FORT WAYNE: April meeting—Joint meeting of ASME, ASLE, & SAE members, with R. W. Wayman, Warner Gear Div., Borg-Warner Corp., speaking on The Ford-Mercury Automatic Transmission. A conducted tour through the Engineering Laboratory of International Harvester Engineering Division preceded Mr. Wayman's talk. (Submitted by J. W. Sites, Vice-Chairman.)

KINGSPORT: March meeting—Annual meeting and election of officers (See ASLE Directory), together with a movie entitled "Touring Tennessee." (Submitted by J. E. Fleenor, Sec'y-Treasurer.)

MILWAUKEE: March meeting—A. Sonntag, Alpha Corp., presented a paper entitled The Properties & Uses Of Pure Molybdenum Disulfide As A Lubricant, covering the compound's stability, electrical properties, purity, anti-corrosion properties, thermal stability, coefficient of friction, and the various methods of application. (NOTE: Copies of this paper may be obtained at no charge by writing: The Alpha Corp., 179 Hamilton Ave., Greenwich, Conn.)

April meeting—Annual meeting and election of officers (See ASLE Directory), with J. T. Bugbee, The Texas Co., speaking on Talented Transmissions, in which the growth of the various types of automatic transmissions from their beginning to the present day perfections was traced, together with the various fluids necessary for their successful operation. (Submitted by R. W. Schroeder, Sec'y.)

NORTHERN CALIFORNIA: March meeting—J. H. Frier, Kaiser Steel Corp., Fontana Works presented a paper entitled Lubrication Practices Of A Modern Steel Mill, discussing the training of oiler personnel, specifications and procurements of lubricants, reconciling a multitude of equipment, various methods of lubrication, lubricating dispensing equipment, the assignment of responsibilities, and quality controls.

April meeting—C. D. Russell, California Packing Corp., addressed the section on Lubrication Practices Of A Food Cannery, discussing the toxicity of lubricants, application of lubricants to all types of can-closing mechanical devices, behavior of lubricants in relation to speed of

(Continued on page 163)

Book Reviews

KNOW YOUR CARBURETOR
by Research Staff, Gumout Div., Pennsylvania Refining Co., Publisher, 2695 Lisbon Rd., Cleveland 4, Ohio, 1953, 46 pages, illustrations, price: No Charge.

Profusely illustrated, KNOW YOUR CARBURETOR describes in non-technical language the basic functions of the carburetor, its various parts, and the typical carburetor troubles usually encountered and how to correct them. The importance of cleaning the carburetor regularly is emphasized.

(Continued on page 169)

Coming Events

JUNE

7-12 Socy. of Automotive Engineers (Summer Meeting), The Ambassador and Ritz-Carlton Hotels, Atlantic City, N. J.

15-17 Amer. Socy. of Agricultural Engineers (46th Annual Meeting), William Penn Hotel, Pittsburgh, Pa.

15-19 Amer. Inst. of Electrical Engineers (Summer General Meeting), Chalfonte-Haddon Hall, Atlantic City, N. J.

15-24 Lubrication Engineering Short Course, Tech. Inst. of Northwestern Univ., Evanston, Ill.

16-26 Lubrication Engineering Short Course, Mass. Inst. of Tech., Cambridge, Mass.

28 to July 2 Petroleum Equip. Suppliers Assn. (Annual Meeting), Broadmoor Hotel, Colorado Springs, Colo.

29 to July 3 Amer. Socy. for Testing Materials (Annual Meeting), Chalfonte-Haddon Hall, Atlantic City, N. J.

APRIL 1954

5-7 American Society of Lubrication Engineers (9th Annual Meeting & Exhibit), Netherlands Plaza Hotel, Cincinnati, Ohio.

Personals

W. H. NASH has been appointed authorized district representative for C. A. Norgren Co. in Michigan, with headquarters at 10300 Grand River Ave., Detroit.

Ehret & Kinsey, Chicago, who represent the Cleveland Worm & Gear Co., manufacturers of Cleveland Worm Gear Speed Reducers, and The Farval Corp., manufacturers of Centralized Lubricating Systems, has announced the opening of a Milwaukee office at 2400 W. Clybourn, telephone DIvision 2-7844, with J. A. GRAMLING in charge.

H. A. NEFF has been named a new district sales representative for C. A. Norgren Co. in Indiana, with headquarters in Fort Wayne and Indianapolis.

A. A. PROBECK, well-known in the metals industry having maintained offices as A. A. Probeck & Co. in New York, Boston, Philadelphia and Washington, has been elected Vice-President of Snap-Tite, Inc., Union City, Pa., manufacturers of a full line of quick-connect disconnect couplers for all industrial, domestic, and farm uses.

Current Literature

A LOW TEMPERATURE SLUDGING TEST
by J. G. McNab, SAE Annual Meeting, Jan. 12-16, 1953 (Preprint).

The Standard Oil Development Company has developed a new test for evaluating the sludge handling ability of lubricants. This Oil Sludging Test measures the sludge handling ability of lubricants in terms of the time required to reach 50% oil screen plugging in cyclic laboratory engine operation. The manner in which sludge builds up in this test is similar to the way it builds up in field engines. Results correlate very well with those obtained in low temperature, stop-and-go field service.

A STUDY OF SOAP AEROGELS FROM LUBRICATING GREASES
by W. H. Peterson & A. Bondi, Journal of Physical Chemistry, Vol. 57, No. 1, Jan. 1953, pp. 30-35.

For a more complete understanding of lubricating greases, a precise knowledge of the nature of the soap structure and its interaction with the oil component was desired. Therefore, the unchanged soap skeleton of a grease was isolated using Kistler's technique of obtaining aerogels. This technique involves removal of the fluid after the system has been heated above the fluids critical temperature. Reconstitution, i.e., replacement of the original oil into the skeleton, led to a grease which closely duplicated the properties of the original, thus indicating the reversibility of the system. Reconstitution with other oils showed grease consistency to depend upon the viscosity and the purity of the oil used. Consistency was found to increase linearly with the logarithm of the oil viscosity, but decreased as the oil contained larger amounts of adsorbable impurities.

ANTIOXIDANT FOR MINERAL OILS
by G. Verberg & J. D. Weevers, Chemical Abstracts, Vol. 47, No. 2, Jan. 25, 1953, p. 856.

The so-called "acid oils" obtained by acidifying alkalene extracts of Dublis cracked naptha and consisting chiefly of cresols and thiocresols, are reacted with olefins. Product is separated by fractional distillation and may be added to lubricants and insulating oils.

CLOUD POINT TEST FOR LOW-TEMPERATURE LUBRICATING OILS
by E. Kanda & T. Haseda, Library Bulletin of Abstracts (Universal Oil Products), Vol. 28, No. 8, Feb. 25, 1953, p. 32.

Method of determining the cloud point by cooling sample and examining it for turbidity is imperfect. The thermometer is immersed in the bottom of the test tube, so that the exact temperature of the sample is hardly known due to the poor conductivity of the sample in the course of heating or cooling. A new method for cloud point determination developed by the authors is based on the photoelectric measurement of the intensity of light transmitted through oil at various temperatures. Even slight changes in turbidity can be detected.

DETERMINATION OF MOISTURE IN OILS & GREASES
by R. Y. Meelheim & J. N. Roark, Analytical Chemistry, Vol. 25, No. 2, Feb. 1953, pp. 348-349.

Roberts and Levin method for determining small amounts of water by distillation through closed systems to a receiver where distillate is titrated with Karl Fischer reagent was useful. But distilling large quantities of solvent for 1-2 hrs. to dry solvent, purge water and transfer all the water to receiver for titration was found necessary, and this prevents the use of this method for routine control. To eliminate this fault certain refinements have been made in the procedure which increase the accuracy, precision, and speed of the determination. These refinements are: the use of an efficient fractionation column; a method of heating the column, tubes, and condenser; and a better azeotrope former. The apparatus shown accomplishes the above objectives, and gives highly accurate and reproducible results. Much less time is required for an analysis using the refined apparatus.

FLUIDS FOR HYDRAULIC POWER TRANSMISSION
by A. E. Bingham, Journal of the Institute of Petroleum, Vol. 39, No. 349, Jan. 1953, p. 47 A.

The desirable properties of hydraulic fluids based on petroleum castor oil, water-glycol, halogenated, and synthetic compounds are summarized for aircraft, marine, and land use. Techniques for flushing systems are given to enable fluids to be changed.

FUEL GAIN WITH LOW VISCOSITY OILS
by J. G. Withers, Scientific Lubrication, Vol. 5, No. 2, Feb. 1953, p. 30.

The viscosity of the lubricating oil at the

(Continued on page 162)

Lubrication Summarized

SOME RECENT DEVELOPMENTS IN AUTOMOTIVE ENGINE LUBRICATION

by N. T. Brenner, Gulf Oil Corp., ASLE Wheeling Section Meeting.

A number of types of crankcase lubricating oils are available for automotive applications. Some of these were originally developed for use in Diesel engines but have been found to be extremely beneficial in certain severe types of service with spark ignition engines generally referred to as gasoline engines.

About five years ago the Gulf Oil Corporation initiated experiments involving the effects on engine cleanliness of using varying proportions of different additives in crankcase oils. In laboratory engines operating at low water jacket and crankcase temperatures, comparable to those in average stop-and-go service, it was clearly demonstrated that certain types of base oils compounded with properly selected detergent-dispersant additives in generous proportions produced phenomenally clean engines. There appeared to be an optimum level of additive concentration below which results were unsatisfactory and above which negligible improvement could be observed. This optimum level of detergency is in the range of "Sup. 1 Oils" (high detergency oils of the type and detergency level previously approved under U. S. Army Spec. 2-104B Supplement No. 1).

After considerable additional laboratory work this development was checked in full scale fleet tests. Approximately 160 of Gulf's salesmen's cars were divided into groups having comparable operating conditions. This fleet test covered a three year period averaging approximately 30,000 miles on each car in typical stop-and-go service. Each group used a different oil. From an engine operated 29,744 miles on a Regular motor oil, it was found that the oil rings were badly plugged and the screen almost entirely clogged; from an engine operated 33,984 miles on a good Premium oil, very little improvement was noted; from an engine operated 32,757 miles on a Heavy Duty motor oil meeting MIL-O-2104, but not of the higher Sup. 1 detergency level, some improvement was observed; from an engine operated 32,003 test miles on an oil of Sup. 1 detergency level, the appearance of the screen and pistons indicated almost complete absence of deposits commonly associated with low temperature engine operation. It was concluded that a Sup. 1 level of detergency, using the proper base stock and carefully selected additives, is the optimum for low temperature operation. Although cars on Sup. 1 oil took longer to break in and, therefore, used a little more oil for the first 5,000 miles, at the end of a 30,000 mile test period the average of all engines using Sup. 1 oil was about 675 miles per quart while the average of those on Premium oil was only 450 miles per quart. It is clear that engines which are overhauled because of excessive oil consumption may be operated for much longer periods between overhauls on high detergency oil.

The question regarding the potential effects of placing detergent oils into dirty engines brings up one of the most persistent bugaboos in the industry. Gulf first attempted to investigate back into reported cases where engines were alleged to have failed for this reason. Strangely enough, they were unsuccessful in obtaining first-hand information which established this supposed purging effect of detergent oil as the definite cause of a single recent failure. Most of the cases appeared to be based on hearsay or circumstantial evidence. They could not investigate cases reported to have occurred several years ago, of course, and cannot, therefore, state that some of the original detergent oils could not have produced trouble.

Gulf then attempted to wash down deposits by introducing detergent oils into engines which were known to be dirty. All of their various Heavy Duty oils were used in this investigation as well as some experimental oils of very high detergency. Not only did all of these oils fail to bring down deposits, but none of them were observed to have done a very significant cleaning job. This in spite of some claims that such oils will clean up dirty engines. It should be reiterated that even high detergency motor oils cannot be expected to clean up engines which have been previously operated on less effective types of oil. Certainly no oil can replace the damage which has been done by the corrosion and wear incident to low temperature operation with ordinary motor oils. To derive the full benefits obtainable with high detergency oils, they should be used continuously throughout the life of the engine.

CHOOSING LUBRICANTS FOR STEEL PLANT EQUIPMENT

by B. J. Lamport, United Engineering & Foundry Co., ASLE Youngstown Section Meeting.

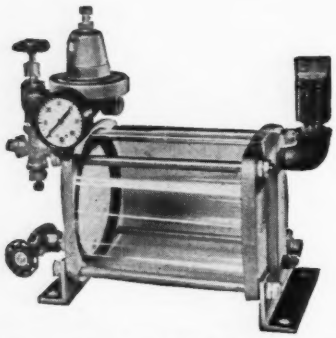
In determining the lubricants for the various pieces of equipment built by the United Engineering & Foundry Company, knowledge of what has and has not proven satisfactory in the past is considered first; other considerations are tooth loading and tooth velocity. The Company's experience has proven that oil in a circulating system should be fed to the point of application at 100 F. for normal operating temperature; that lubricants for all gear reduction units should be the extreme pressure type having a lead napthenate additive, be non-corrosive and non-etching, and should meet the Timken test of 42 pounds minimum. For example, in a blooming or slabbing mill:

For an ingot buggy of dual motor and drive construction with a cone worm having about 50 inches of continuous thread engagement, extreme pressure lead napthenate oil with a viscosity of about 2500 SSU @ 100 F. is recommended. Straight mineral or a compounded oil of acidless tallow does not render proper protection in these units.

Because of the rugged service required of the bevel gears in ingot receiving tables, front and back mill tables, and run out including the shear pull back tables, an extreme pressure oil having a viscosity of 1800/2000 SSU @ 100 F. with a lead napthenate additive is recommended that will drop water freely and still main-

(Continued on page 165)

Lubrication in the News



AIR PRESSURE OPERATED DISPENSER: Specifically designed to serve as central reservoirs of single line, low pressure air operated oiling systems, discharging a regulated amount of oil to individual bearings by means of adjustable sight feed needle valves, these recently developed dispensers are furnished in sizes up to 2 gallons in capacity for floor or wall mounting. The construction features the elimination of oil or air leaks. Extremely sturdy aluminum endshields carry the break-resistant, transparent Lucite reservoir between oil resistant Hygar gaskets. Four heavy overbolts with lock nuts compress these rubber gaskets effecting a positive seal. The oil supply is always visible through the transparent reservoir and shows at a glance when a refill is necessary; a large filler cap makes it easy to replenish the oil; an oil drain plug is provided, and oil filters can be furnished upon request. For further information, write: Oil-Rite Corp., 2328 Waldo Blvd., Manitowoc, Wis., Bulletin 82-11.

FILTERALL, a new permanent-type all-metal filter which eliminates replacement of pack or cartridge and designed to filter — with high efficiency — solids from all liquids or gases, and strip water from various liquids, is molded of carefully sized spherical metal particles, sintered under controlled atmosphere, in various shapes and sizes. Filtration removing all contaminants over 2 microns from any liquid is accomplished with a minimum pressure drop; when used for filtration of lubricating oils neither detergents nor additives are removed—only abrasive and harmful sludge. Satisfactory tests have been made on applications ranging from the smallest size guided missile hydraulic system (operating pressures up to 6000 psi; temperature range from —65 to +400 degrees) to bulk diesel fuel, gasoline, and jet fuel filters of 600 GPM capacity. For further information, write: Permanent Filter Corp., 2309 Riverside Dr., Los Angeles 39, Calif.

LEVER-TYPE GREASE GUNS: Four new giant-size lever-type grease guns, holding 40 to 100 per cent more lubricant than ordinary grease guns, have been announced that can be refilled in seconds from a Lincoln Filler Pump or by suction. Sizes available: two 21 oz. capacity guns developing 10,000 lbs. pressure; a 32 oz. capacity gun, 10,000 lbs. pressure; and a 32 oz. capacity volume-type gun, developing 4,300 lbs. pressure. All models include long hydraulic coupler extension for ease in contacting hard-to-reach fittings, and filler nipple for refilling guns from a filler pump. For complete details, write: Lincoln Engineering Co., 5743 Natural Bridge Ave., St. Louis 20, Mo., Bulletin 718.

METAL HOSE TECHNICAL DATA BOOK: Edited to satisfy both the engineers' and purchasing agents' want for information, this compact, yet complete, data book includes information on application, temperature ranges of various types of metal and wire braided hose, dimensions, couplings, and assemblies. Types of Universal flexible metal hose illustrated and described include: seamless all-metal flexible pressure hose; inter-locked suction, blower and conveyor hose; square-locked conduits and flexible spout tubing; high pressure hydraulic hose; double wire-braided hose for high pressure; single wire-braided hose for medium and low pressure; and others for special applications of vibration elimination, steam, and gas stove connectors. Copies may be obtained by writing: A. M. Younger, Universal Metal Hose Co., 2133 S. Kedzie Ave., Chicago 23, Ill.

METERFLO OIL CIRCULATING SYSTEM, a newly developed circulating system utilizing the Trabon positive piston displacement principle, assures controlling the flow of oil to every bearing under pressure. Features: flow rates up to 80 cubic inches per minute; RTP-2000 series rotary type pump units available in complete range of discharge capacities; pump units with or without sumps include motor, pump, hi-lo dual acting pressure switch; cartridge type filter, pressure gauges, oil level gauge, and fill screen; sturdy sump units include removable baffles for easy cleaning of tank; type MXO and MO metering valves accurately control flow of oil to each bearing in the system; pair of constantly blinking lights, actuated by flow of oil, available as optional signal equipment: the hi-lo pressure switch, connected to the warning lights, permits ready identification of too-high or too-low pressure, blocked line, low oil supply, or will shut down the machine being lubricated. For further information, write: Trabon Engineering Corp., 1814 E. 40th St., Cleveland 3, Ohio, Bulletin 531.

MOLYKOTE, Type U, a new grease consistency mixture for extreme bearing pressure lubrication at temperatures ranging from —40 F. to approximately 400 F., has been announced that is identical to the company's Molykote, Type G, except that instead of a petroleum lubricant being utilized as a carrier, polyalkylene glycol is used instead. Particularly adaptable for use in extreme temperature applications in aircraft and as lubricant for rubber shaft seals rotating at speeds as high as 8000 RPM, it can be used for temperatures up to approximately 800 F. in which case the carrier evaporates, leaving the Molykote powder impregnated on the surface for lubrication. For further details, write: The Alpha Corp., 179 Hamilton Ave., Greenwich, Conn.

MULTI-LUBER, a new install-it-yourself centralized lubrication system for punch presses, has been designed to service anywhere from 5 to 12 bearings on standard inclinable or straight side punch presses and other similar types of production machines. The manually-operated Multi-

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Patent Abstracts

Prepared by ANN BURCHICK from OFFICIAL GAZETTE, Vol. 667, No. 4; Vol. 668, Nos. 1, 2, 3, 4, 5,; Vol. 669, Nos. 1, 2, 3. Printed copies of patents are available from the Patent Office at twenty-five cents each. Address the Commissioner of Patents, Washington, D. C. for copies and for general information concerning patents.

CORROSION INHIBITORS, Patent #2,629,676
by C. F. Prutton, assignor to The Lubrizol Corp.
A corrosion inhibitor for metal surfaces comprising the combination of an oil-soluble organo-metallic phosphide, which compound has a metal substituent solely attached to phosphorus and contains at least one organic radical selected from the class consisting of hydrocarbon and halogen-containing hydrocarbon radicals, and a non-aqueous oil vehicle.

GREASE MANUFACTURE, Patent #2,629,691
by W. H. Peterson, assignor to Shell Development Co.
In the process for the praparation of a grease comprising lubricating oil, a gelling amount of a colloidal metallic oxide gel in highly expanded form and capable of forming a grease with said oil and a hydrophobic surface active agent, the improvement which comprises heating said ingredients at a temperature between about 165 and about 200 C. for a period between about 30 minutes and about 120 minutes.

GREASE, Patent #2,629,692
by H. J. Liehe, assignor to Standard Oil Co.
An anhydrous grease containing less than 0.1% water, consisting essentially of from 0.25% to 15% of an alkaline earth soap of a preferentially oil-soluble sulfonic acid, from about 1% to about 15% of an alkaline earth soap of a fatty material, and a viscous hydrocarbon oil, said alkaline earth soap of a preferentially oil-soluble sulfonic acid and said alkaline earth soap of a fatty material being used in a ratio of from about 1:2 to 2:1.

LUBRICATING COMPOSITION, Patent #2,629,693
by R. C. Barton, R. F. Bergstrom & J. M. Plantfeber, assignors to Shell Development Co.
A finished liquid lubricating composition for use in engines operating on high sulfur fuel comprising a major amount of a mineral lubricating oil; a calcuim salt of petroleum sulfonic acid in an amount of from about 1% to about 4% calculated as sulfate ash and minor amount of from about 1% to about 4% by weight of phenyl alpha naphthylamine and 2,6 ditertiary buty1-4-methyl phenol.

GREASE COMPOSITION, Patent #2, 629, 694
by H. A. Woods & J. A. Edgar, assignors to Shell Development Co.
A grease composition comprising a major amount of a lubricating oil having incorporated therein a minor amount of an alkali metal soap and from about 0.01 to 5% of an oil-soluble aryl amine and from about 0.01 to 2% of an oil-soluble polyvalent metal salt of an alkyl dithiocarbamic acid.

MANUFACTURE OF LITHIUM LUBRICATING GREASES, Patent #2,629,695
by J. B. Matthews, D. Evans, W. D. Carswell & J. F. Hutton, assignors to Shell Development Co.
In a process of preparing a stable non-bleeding grease comprising an oleaginous vehicle gelled to a grease structure with a lithium soap of a higher fatty acid, the steps comprising heating said oleaginous vehicle and lithium soap to a temperature between 210 and 260 C. until a homogeneous composition is formed, cooling the composition to an equilibration temperature between the temperatures of the two lowest phase transformation points which occur above 50 C., isothermally tempering the grease between said transformation points for a period between about 1 and about 6 hours and thereafter cooling and homogenizing the grease.

SULFURIZED FATTY & WAXY MATERIALS, Patent #2,629,721
by C. J. Sunde, assignor to N. I. Malmstrom & Co.
A process of making leaded sulfurized saponified degras which comprises heating wool grease to about 270 to 280 F. in the presence of about 10% caustic soda for about one hour, and the caustic soda being in a concentrated solution in a minimum amount of water, drying the hot reaction mixture by adding it to a lubricant oil and blowing with hot air at a temperature of about 285 F., about 100 to 125 parts of the reaction mixture being placed in about 75 parts of the mineral oil, then mixing with a slurry of about 23 parts of phosphorus penta-sulfide and 25 parts of mineral oil and maintaining with stirring a temperature of 285 to 300 F. and then treating the thus sulfurized saponified wool grease with a solution of lead acetate at a temperature of about 200 to 212 F. and finally removing the acetic acid.

FAT COMPOSITION, Patent #2,630,408
by C. H. Lighthipe, W. M. Nothum & C. E. Retzsch, assignors to Nopco Chemical Co.
A composition of matter which comprises the sulfated derivatives of a mixture having a viscosity less than 2500 Saybolt seconds at 100 degrees Fahrenheit of 100 parts by weight of a naturally occurring fat and from 20 to 200 parts by weight of a blown fat selected from the group consisting of natural moellon degras and dry blown artificial moellon degras, and said sulfated derivatives having an organic SO_3 content of from about 1 to about 6 per cent based on the weight of the sulfated derivatives.

TETRAFLUOROETHYLENE POLYMER COMPOSITIONS CONTAINING CHLORINATED LUBRICANTS, Patent #2,630,-417
by J. F. Lontz, assignor to E. I. du Pont de Nemours & Co.
A non-aqueous pressure-coalescing composition comprising tetrafluoroethylene polymer particles of colloidal size intimately admixed with a nuclear-chlorinated aromatic compound containing from 15% to 65% by weight of chlorine and having a melting point within the range of —20 C. to 150 C. and a boiling point below 450 C. at atmospheric pressure, said tetrafluoroethylene polymer containing more than 85% by weight of polymerized tetrafluoroethylene, said chlorinated compound being present in an amount equal to from 5% to 50% of the combined weight of the said tetrafluoroethylene polymer and chlorinated compound.

SULFURIZED TALL OIL-CONTAINING COMPOSITIONS, Patent #2,631,129
by S. P. Waugh, assignor to Tide Water Associated Oil Co.
A composition, adapted for use as a cutting oil, comprising in major amount based on the weight of said composition a lubricating oil from the group consisting of mineral oils and sulfurized mineral oils, an oil-soluble sulfurized tall oil in an amount sufficient to improve the lubricating qualities of said lubricating oil but having a tendency to form deposits adherent to metals in contact therewith, and an oil-soluble metal salt of an alkyl cycloaliphatic dithiophosphate in an amount sufficient to inhibit said composition against formation of adherent deposits on metals in contact therewith.

MINERAL OIL ADDITIVE, Patent #2,631,130
by J. H. Bartlett & T. Cross, Jr. assignors to Standard Oil Development Co.
A mineral oil containing dissolved therein 0.01 to 15% of a member of the class consisting of: (A) the products obtained by reacting a combination of the elements sulfur and phosphorus with an ester of an alcohol selected from the group consisting of alcohols.

STABILIZED COMPOSITIONS CONTAINING SULFURIZED ESTERS OF TALL OIL, Patent #2,631,131
by S. P. Waugh, assignor to Tide Water Associated Oil Co.
A composition consisting essentially of a mineral oil having dissolved therein a sulfurized esterified tall oil in an amount sufficient to improve the lubricating qualities of said oil but which has a tendency to form deposits adhesive to metals in contact therewith and an oil-soluble metal salt of an ester of thiophosphoric acid in an amount sufficient to inhibit said composition against said formation of metal adhering deposits.

LUBRICATING OIL ADDITIVE, Patent #2,631,132
by J. P. McDermott, assignor to Standard Oil Development Co.
A composition consisting essentially of a mineral lubricating oil and 0.01 to 2% by weight of a compound.

METALWORKING LUBRICANT SOLUTION, Patent #2,631,978
by F. C. Bersworth, Verona, N. J.
A wire drawing lubricant solution for beryllium-copper alloys, said solution consisting of an aqueous solution of the di-

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ASLE Officers & Directors

The following officers and directors were elected at the ASLE 8th Annual Meeting & Exhibit held in Boston, Massachusetts, on April 13-14-15, 1953, to serve the American Society of Lubrication Engineers during the 1953-1954 term of office.

President
W. E. Campbell
Bell Telephone Labs.

V. Pres., Eastern
M. E. Dougherty
Acheson Colloids Co.

V. Pres., Midwestern
J. W. Hopkinson
Penn-Petroleum Corp.

V. Pres., Western
P. S. Adams
Gen. Petroleum Corp.

V. Pres., Canadian
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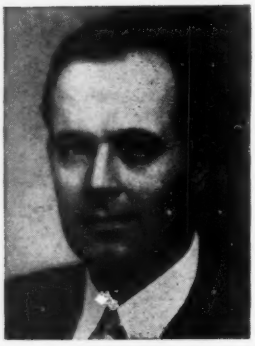

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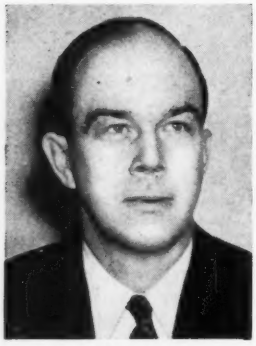

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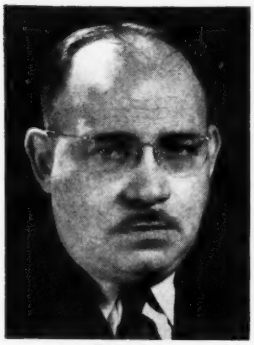

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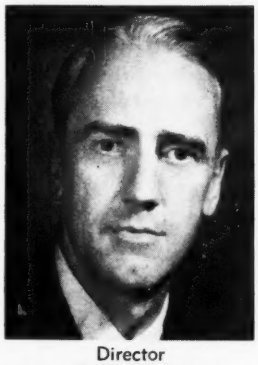

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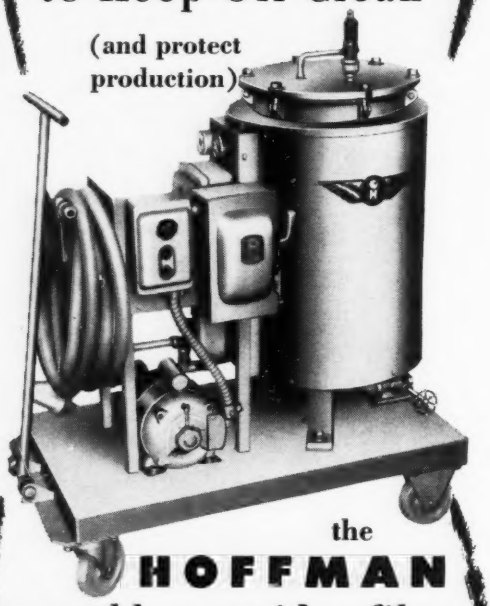

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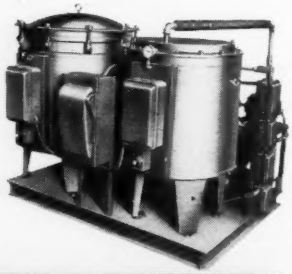

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(Booser - Wilcock, Continued from 143)

tions. The requirement of high viscosity petroleum oil in greases for long life has been demonstrated in many high temperature ball bearing life tests conducted in our laboratory. Variation in surface tension of petroleum oils and of many synthetic oils is of a much lower order of magnitude, and its effect on grease life is not conclusive. The tendency of low surface tension silicone oils to creep away from silicone greased bearings, however, probably has resulted in shortening of the long life potentially available with silicones in high temperature applications.

The effect of speed and load on grease life in ball bearings may also be predicted from these minimum oil studies. Thus, the life of a greased bearing under different operating conditions might be determined by relating the bleeding and evaporation characteristics of the grease to the minimum oil requirements of the bearing.

Determination of minimum oil requirements is useful in analyzing bearings themselves. The great difference in lubrication requirements of similar No. 306 size ball bearings is apparent from Table I. The best ABEC-1 bearing tested, for instance, ran eight times as long on one milligram of oil as the poorest of the group. The best results were obtained with a bearing of outstanding field reputation for quiet operation and lack of vibration. The bearing precision, as defined merely by ABEC rating, is not necessarily related to the amount of lubrication required; for example, very good results were obtained with a set of bearings specially constructed to be poorer than ABEC-3 limits but within ABEC-1 tolerances. Thus, lubrication requirements are dictated not so much by superficial dimensional fit-up as by the overall construction and finish of the bearing. Bearing quality might also be evaluated through the minimum oil film for coverage of the surface as w_0 although this was not done for the different types of bearings used in this study.

In mist lubrication, as in ball bearing lubrication, satisfactory operation depends on the presence of minute quantities of lubricating oil. Here again, the necessary rate of oil feed to the working parts of the bearing is represented by the differential Equation (10). An additional quantity would have to be supplied, however, since a large proportion of the mist would not be expected to reach and lubricate the sliding parts of the bearing.

Although very little oil is needed for actual lubrication of ball bearings, additional lubricant supply is frequently necessary for cooling. Large high speed bearings, for instance, may be preloaded to the extent that they seize if heat generation causes differential thermal expansion. In mist lubrication, the cooling effect is largely obtained from the air flow, while the mist supplies the lubricating oil.

SUMMARY: The running time of a ball bearing on a small quantity of lubricating oil varies exponentially with the quantity of oil present. Oil films of less thickness than that required to cover the surface roughness of the bearing parts provide poor operation and very short life. For quantities of oil greater than this minimum film, the running time increases as the logarithm of a dimensionless oil utilization factor, so that for a given quantity

of lubricating oil, the running life increases with increasing oil viscosity, with increasing oil surface tension, and with decreasing power loss in the bearing. Correlation has been obtained with various factors involved in grease lubrication, and the results are believed to be of utility in determining bearing quality and in the study of oil mist lubrication.

Further work is necessary with various oils, additives, and different bearing sizes together with simultaneous power loss measurements to expand and clarify these results. Study of the mechanism by which oil is lost from a bearing should also be fruitful. Correlation with ball bearing grease life test results may be useful for predicting grease life under a wide variety of operating conditions.

NOMENCLATURE

- a : Constant $= t_o w_o^{-n}$
- D : Bearing bore, mm.
- f : Friction factor.
- H : Friction power loss in bearings, Kg.m/sec.
- $\triangle H_v$: Heat of vaporization, cal./gm.
- k : Proportionality constant between oil vaporization energy and friction energy, $1.18 \times 10^{-7}\ w_o \triangle H_v / t_o H$.
- N : Bearing speed, rpm
- n : Exponent of w in expression for running life $t = aw^n$.
- t : Running time to failure, hours.
- t_o : Running time to failure with w_o, hours.
- U : Dimensionless oil utilization factor, $1.02 \times 10^{-10}\ (\mu\tau/\varrho H.)$
- w : Weight of lubricating oil added, milligrams.
- w_o : Minimum weight of oil for surface coverage, milligrams.
- μ : Viscosity of lubricating oil, centipoises.
- ϱ : Density of oil, gm/cc.
- τ : Surface tension, dynes/cm.

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COMMENTARY by D. Lindquist, Marlin-Rockwell Corp.: Through the methods presented in this paper we have calculated the relationship between running time, and quantity of lubricating oil, with race curvature as a parameter. Race curvature is a measure of how closely the ball fits a cross section of the raceway and is usually expressed by the equation $c = r/d$ where c = race curvature, r = radius of race curvature and d = ball diameter.

The term "H" in Equations (7) & (9) is the friction power loss in the bearing expressed in Kg. m/sec. and this power loss term is intimately associated with the curvature. It is well known that true rolling motion occurs at two points in the region of contact between a ball and the raceway. Adjacent to these two points are areas where slippage occurs. As the raceway fits the ball more closely, these slippage bands become more extensive and cause a larger friction power loss in the bearing. Muzzoli in Ref. 5 has evaluated friction torque in terms of race curvature. These values of friction torque were used in the method set forward in the subject paper to obtain an expression for running time of a 306 size bearing as a function of the quantity of oil. The following conditions were selected for this calculation. Lubrication: 1065 petroleum oil, Speed: 3600 RPM, Load: 160 Pounds Radial, Race Curvatures: .53 inner and outer and .51 inner and outer.

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For curvatures of .51, $t = 1.0\ w^{2.4}$; for curvatures of .53, $t = 2.5\ w^{2.7}$, where t = running time in hours and w = quantity of oil in milligrams.

The following tabulation shows the running time for various quantities of oils for the two different curvatures:

w	t (.51 curvatures)	t (.53 curvatures)
.35 milligrams	.08 hours	.15 hours
1.00	1.0	2.5
2.00	5.3	16

Experimental confirmation of effect of race curvatures on life of bearing under conditions of minimum lubrication would be interesting.

(Feng - Rightmire. Continued from page 136)

sheet, this disturbance would produce a relative slip of about 0.0015 in. under the otherwise same conditions. The testing surfaces of the steel specimens were not damaged by the oscillatory disturbance.

Another way of averting mechanical wear is to reduce the load to such a small value that none of the contacting high spots is plastically deformed. Such a load is extremely small and this method is impractical. In the ordinary atmosphere, however, metallic surfaces are always contaminated by adsorbed gases, oxides, greases, etc. It is possible, therefore, to add to the metallic surface a film which can be solid, or fluid or semi-fluid and at the same time to adjust the load so that the roughening of the interface of contacting high spots due to plastic deformation does not exceed the thickness of the surface film (cf. Fig. 2c of Ref. 1). Tomlinson[4] reported the following results in 1927: When a polished steel sphere which rubbed against a polished steel surface was smeared with vaseline or castor oil, surface damage did not occur with a low normal load, but did occur under a heavy load. This result shows that wear can be stopped by reducing the normal load. It is in agreement with the hypothesis just stated that a low load produces a roughening of the surface less than the thickness of the lubricant film.

This hypothesis also explains the seemingly contradictory results regarding lubricants reported by various workers in this field. In one report, a certain lubricant is found to be very effective in checking or retarding fretting, and in another report, the same lubricant has no noticeable effect. One must look into the conditions under which different investigations were carried out. It is not justifiable to compare two research results which have only one condition in common, the same lubricant. In fretting phenomenon, a lubricant which helps in reducing or checking fretting if the load is comparatively small will become ineffective under heavy load. The smallness of the relative motion in most fretting cases, gives additional difficulty in repairing the worn surface film even with fluid lubricants. An experiment with a relatively small distance of travel (equivalent to a small number of cycles) may indicate a good result about the effectiveness of a certain lubricant, while another experiment with an extremely long distance of travel may show that this lubricant does not help in reducing fretting damage. The ineffectiveness of lubricants in reducing fretting damage may also be due to the increased slip between the surfaces as a result of the presence of lubricant.

Experience tells us that lubricants are generally ineffective in reducing fretting damage. Use of this experience as a basis for supporting the idea that fretting has no relation to mechanical wear is obviously unsound.

Fretting has been and still is frequently called "fretting corrosion" or "friction oxidation." These misleading terms have led many investigators to try to stop fretting damage by eliminating chemical reaction. Such investigations always show that fretting damage cannot be stopped entirely by eliminating chemical action. This indicates that chemical action is not the primary cause of fretting. If oxidation were the primary cause of fretting, elimination of oxygen in the surrounding atmosphere would eliminate fretting completely. From the mechanism proposed here, the conclusion is that elimination of oxidation merely reduces fretting damage, since it cannot stop the initiation of damage due to the primary cause of fretting, mechanical wear. This can also be seen clearly by drawing a vertical line $CC_1C_2C_4C_3$ in Fig. 4(a). C_4 represents the fretting damage. Elimination of oxidation will reduce the damage from C_4 to C_2. In addition to the elimination of oxidation, eliminating accumulation of wear product will remove C_1C_2 and reduce the wear from CC_2 to CC_1.

Minimization of oxidation can be easily accomplished by performing experiments in an inert atmosphere, in vacuum, or in an inert liquid medium. Sakmann and Rightmire[2] studied qualitatively the difference in damage between specimens tested in vacuum and in air. Their results indicated that there was less damage in vacuum than in air, and less in an inert atmosphere than in oxygen. Feng and Uhlig's quantitative data[5] confirm their finding.

In investigating the effect of the wear product, Sakmann and Rightmire[2] used a combination of hard and soft metals so that the hard oxide particles could be embedded in the soft metal. Fretting damage was thus reduced, but not eliminated.

DISCUSSION: The agreement between the proposed shape of the Fretting Damage vs. Distance of Travel Curve (Fig.4b) and the shape of the experimental curve supports the idea that fretting begins with metallic wear, then goes through a shifting period in which accumulation of trapped wear particles shifts the wear action gradually to abrasive action, and finally it reaches the abrasion stage in which damage is almost entirely caused by abrasion. To formulate fretting damage is not easy, though the formulation[6] of wear and metal transfer based on the idea given in Ref. 1 is already available. For formulating the fretting damage, the idea of picturing the total damage as the sum of two independent components, the mechanical component and the corrosion component, is not useful. The reason is that under conditions of vanishing mechanical component, the total observed damage becomes insignificant.

Diverse opinions have been expressed regarding the significance of the alternating nature of the relative motion to the fretting damage, because it has not been fully appreciated that fretting starts with ordinary wear. In the early stage of fretting under any circumstances, the reciprocating nature of the motion makes no difference. As the action progresses, however, the small-amplitude

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oscillations cause the wear particles to be trapped and to accumulate. The action thus passes through a transition period, eventually reaching the stage at which damage is caused principally by abrasion.

It is interesting to point out that the idea of mechanical abrasion has been rejected by Tomlinson, Thorpe and Gough[7] because their experimental results based upon visual estimate of fretting damage show no significant dependence of damage upon the normal load in the range from 25 to 225 lb. corresponding to a pressure range from 3 to 27 tons per sq. in. Contrary to their conclusion, Feng and Uhlig's quantitative data[5] indicate that, at constant relative slip, fretting damage increases with normal load.

Tomlinson[6] suggests that "fretting corrosion" is the corrosion caused by the molecular attrition which is considered to be sufficiently high to detach individual molecules from the surface. According to him, molecular attrition is independent of external forces and hence "fretting corrosion" is not influenced by the normal load, which does not agree with Feng and Uhlig's quantitative data mentioned above. Furthermore, he uses the term "individual molecules" to make distinction from finite particles and suggests that a molecule dislodged from the surface is oxidized very quickly. However, electron-microscopic examination of fretting product[8] shows that the particles are far larger than molecular size.

Godfrey[9] attributes fretting damage to adhesion. The idea of adhesion has been used in the "welding" theory of friction advanced by Holm[10], Merchant[11], and Bowden[12]. The adhesion between two oxide-covered surfaces is highly questionable, and it also gives the difficulty in explaining the formation of any loose particles in either wear or fretting (cf. Ref. 1).

Throughout this paper, weight loss is considered as a measure of fretting damage. The reason is that it can be measured quantitatively and relatively accurately. However, weight loss is not always the best measure of fretting damage. An excellent example is the case in which two clean surfaces rub against each other in vacuum with an alternating relative motion. Because of adhesion between clean metallic surfaces in vacuum, the peak sheared from one high spot sticks to the opponent high spot and becomes a piece of transferred metal. Thus very little loose wear material can be produced, metal merely being transferred back and forth from one specimen to another. If the specimens are made of the same material, the weight loss of each is practically nil. Nevertheless, both specimens are subject to serious damage caused by metal transfer.

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[11]M. E. Merchant. J. Appl. Phys. 11, 230, 1940.
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(Annual Meeting Abstracts, from 133)

tempt to show how the customary engineering equation used for predicting viscosities of fluid lubricants under high pressures can allow serious errors when the pressures are large enough. Examples of bearing conditions will be used to emphasize a need for a more correct yet practical formulation which engineers can use to predict viscosities of fluid lubricants under very high pressures.

VISUAL ANALYSIS OF ENGINE SLEEVE BEARING TROUBLE
by E. C. Crankshaw & W. A. Weinkamer

Cleveland Graphite Bronze Co.

For the experienced and trained eye, most bearing failures may be placed in one of the general catagories of common operation and installation ills. Further study of the engine operational history, maintenance log, and its present condition will narrow down the possible causes of the trouble. These logical steps in visual analysis include not only inspection with the naked eye, but also those quick, simple, tests which may be made with the aid of portable instruments, such as a microscope, micrometers, magnets, or other tools which do not call for partial destruction of the bearing and the evidence it presents.

Sleeve bearing failures are commonly cataloged into four general classes, namely: Fatigue, Seizure & Wiping, Corrosion, and Wear. However, to these it seems necessary to add a special "gremlin" which not only can be in a failure class of its own, but is has a freakish ability to lose its true identity and end up under one of the aforementioned general classifications. This scourge of bearing and engine manufacturers is known to all as "Dirt," or "Foreign Particles."

This paper will cover Chemical, Metallurgical, and Mechanical factors which, having lead to bearing failures, may be recognized visually and cataloged as above. This material will concentrate on recognition of the causes of failure and the corrective measures required, rather than attempt to define the classification of failure metallurgically.

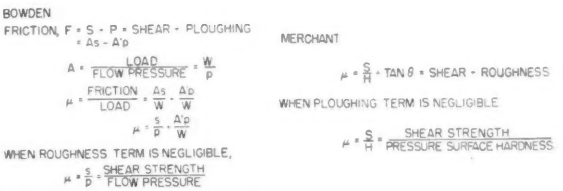
WHAT LUBRICATION MEANS TO THE BUILDER OF MACHINE TOOLS
by J. J. Jaeger

Pratt & Whitney Div., Niles-Bement-Pond Co.

The designer of machine tools is faced with a variety of compromises in order to select suitable lubricating equipment for a machine tool. The desire for automatic lubrication is tempered by price and size. The choice of lubrication medium for gearing, slides and bearings are all different; the choice may be controlled by lubricity or it might be by film thickness or by the co-efficient of friction at slow speeds.

We compound this with a need of a lubricating coolant for cutting, and here the choice broadens due to the wide variety of cutting tools which might be used and even wider variety of materials which might be cut.

AMENDMENT, April, 1953, LE: For both immediate interest and reference, the following illustrations from the paper The Influence Of Solid Surface Films On The Friction & Surface Damage Of Steel At High Sliding Velocities, by E. E. Bisson, NACA, Lewis Flight Prop. Lab., are herewith produced. The content of each illustration is indicated in the title but reference should be made to the original paper for further details.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FRICTION, F = S · P = SHEAR · PLOUGHING
= As · A'p
A = LOAD / FLOW PRESSURE = W/P
μ = FRICTION / LOAD = As/W · Ap/W
μ = S/P · A'p/W
WHEN ROUGHNESS TERM IS NEGLIGIBLE,
μ = S/P = SHEAR STRENGTH / FLOW PRESSURE
MERCHANT
μ = S/H = TAN θ = SHEAR · ROUGHNESS
WHEN PLOUGHING TERM IS NEGLIGIBLE
μ = S/H = SHEAR STRENGTH / PRESSURE SURFACE HARDNESS

Appendix A Friction Theory.

	MOLYBDENUM DISULFIDE $Mo S_2$	TUNGSTEN DISULFIDE WS_2	GRAPHITE C	LEAD IODIDE $Pb I_2$	SILVER SULFATE $Ag_2 SO_4$
MELTING PT. °C	1185	d 1250	3527	402	652
HARDNESS (Mho)	1.0-2.5	FRIABLE	1.0-2.0	-	-
CRYSTALLINE STRUCTURE	HEXAGONAL	HEXAGONAL	HEXAGONAL	HEXAGONAL	ORTHO-RHOMBIC
FORM	LAMINATED	-	LAMINATED	-	-
ORIENTATION	RANDOM	NONE	HIGHLY PREFERRED	NONE	NONE
SOLUBILITY: IN WATER	INSOLUBLE	INSOLUBLE	INSOLUBLE	SLIGHTLY	SLIGHTLY
IN ACIDS	$H_2 SO_4$, Ag. Reg.	HNO_3 + HF	INSOLUBLE	KI	HNO_3, $H_2 SO_4$
CHEMICAL REACTIVITY	MEDIUM	MEDIUM	LOW	MEDIUM	MEDIUM
TENACITY FOR STEEL	HIGH	MEDIUM	LOW	-	-

Appendix B Physical and chemical properties of solid lubricants.

On page 79, lines 6 and 7, Effects Of Modern Design Trends On Ball Bearing Research, by L. D. Cobb, New Departure Div., GMC, this sentence should read: This work is being extended to a temperature range of 100 to 1000 F. for 100 hours.

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(Current Literature, from 150)

running temperature has a pronounced effect on the mechanical losses in the engine and consequently, on the overall efficiency. Roughly speaking, the losses increase as the fourth root of the absolute viscosity at 210 F. On this basis the engine friction losses will decrease by nine per cent for each 10 SAE numbers reduction in viscosity grade. An improvement in fuel consumption of nine per cent will, therefore, be obtained at no load, but as the throttle is opened the importance of friction losses becomes less and the gain in fuel consumption becomes correspondingly smaller. At one-eighth throttle, which is the lowest likely road condition, the gain is six per cent and at full throttle it may be as little as one per cent.

LUBRICATING OIL ANALYSIS BY THERMAL DIFFUSION & MASS SPECTROMETRY

by F. W. Melpolder, R. A. Brown, T. A. Washall, W. Doherty & W. S. Young, Analytical Chemistry, Vol. 25, No. 3, Mar. 1953, p. 523.

High temperature mass spectrometer analyses were used to evaluate the thermal diffusion process for separating light lubricating oils into hydrocarbon types. An eicosane distillate stock containing between 17 and 22 carbon atoms was initially percolated through the silica gel to separate paraffins from aromatics. Each of these fractions was then subject to the thermal diffusion process in batch-wise operations. Significant separations were obtained.

NON-FLAMMABLE HYDRAULIC FLUIDS

by Anon., Chemical Week, Vol. 72, No. 10, Mar. 7, 1953, pp. 68-69.

The specialized liquids are being stalled in certain hydraulic machinery (ingot manipulators, die cast machines) where high temperatures pose a fire hazard. Top consumer of the safety fluids now are die-casting machines. Many of the same firms supplying industrial fluids are also interested in supplying the hydraulic fluids for aircraft. Here the requirements are far more rigorous — and the fluids more costly. Among the products offered industrially are chlorinated hydrocarbons, like the Aroclors (chlorinated biphenyls and polyphenyls) sold by Monsanto. Tricresyl phosphate has been used industrially to some extent. Monsanto's Pydraul F is an organic-phosphate ester type of material, similar to its Skydrol. The cost is still fairly high, $3.75/gal.

PREDICTION OF CRITICAL PROPERTIES & EQUILIBRIUM VAPORIZATION CONSTANTS FOR COMPLEX HYDROCARBON SYSTEMS

by M. J. Rzasa, E. D. Glass & J. B. Opfell, Chemical Engineering Progress Symposium Series, Vol. 8, No. 2, 1952, pp. 28-37.

A correlation has been devised by which the convergence pressures (or the pressures at which equilibrium vaporization constants appear to converge to unity) of complex hydrocarbon systems may be estimated. The correlation is based on the relationship of the critical pressure of system and the product of the molecular weight and specific gravity of the heptanes plus fraction. A chart has been prepared from which the convergence pressure at any temperature for any essentially paraffinic hydrocarbon system may be estimated. Thirty-five references are given.

QUANTITATIVE ISOLATION OF FATTY ACIDS IN PETROLEUM OILS

by L. R. Dickson & R. R. Jay, Petroleum Engineer, Vol. 25, No. 3, Mar. 1953, pp. C-45-46.

Procedure for saponification of the sample with potassium hydroxide and ethanol, separation of the oil free soap solution, precipitation of the "separated acids," and isolation of the fatty acids is given.

SOME ELECTRICAL PROPERTIES OF COLLOIDAL SUSPENSIONS IN OILS

by A. Bondi & C. J. Penther, Journal of Physical Chemistry, Vol. 57, No. 1, Jan. 1953, pp. 72-79.

A variety of electrical measurements have been carried out on colloidal suspensions in oils by means of a capacitor with one rotating electrode. Suspensions of soap fibers exhibited a drop of dielectric constant with increasing shear stress which has been ascribed to flow orientation of these anisometric particles.

SPECTROGRAPHIC & QUANTOMETRIC ANALYSIS OF LUBRICATING OILS

by J. Gillette, Analytical Chemistry, Vol. 25, No. 3, Mar. 1953, p. 525.

A rapid method of determining metallic impurities and additives in lubricating oils is essential for engine wear studies, and as an aid to preventive maintenance. A method of direct spectrographic analysis using the ARL rotating disk electrode was described. A weighed amount of cadmium naphthenate is added to each sample as the internal standard. Approximately 0.5 ml. of sample is required and a complete analysis can be made in 10 to 15 minutes. By recording the spectra on the ARL Quantometer, the analysis time is reduced to about 5 minutes. Complete details of procedure were given.

SYNTHETIC LUBRICANTS — I, ENGINEERING POSSIBILITIES

by W. A. Zisman, Oil & Gas Journal, Vol. 51, No. 43, Mar. 2, 1953, pp. 74-75.

The synthetic liquids which have received greatest attention in the field of lubrication in the past 10 years are the aliphatic esters, the polyalkylene oxides, the silicones, the esters of phosphoric and silicic acids, and the highly fluorine-substituted hydrocarbons. Tables which contain lists of synthetic and reference oils having viscosities of 10 CS. at 210 F., 10 CS. at 100 F., and 1,500 CS. or less at —65 F. are presented.

SYNTHETICS FOR JET ENGINES

by A. L. Foster, Petroleum Engineer, Vol. 25, No. 2, Feb. 1953, pp. C-3-4.

In newer jet designs bearing loads and temperatures have risen seriously, and 450 F. is not uncommon. Oil returning to the lubrication system at 225 F. is typical; cooling becomes a serious problem. Oils need very high viscosity index, low volatility. Organic diesters and polyolefin glycols are chiefly used, as well as high boiling aliphatic monoesters, polyalkylene oxides, polyalkyl silicones and highly substituted fluorohydrocarbons. Table lists components and sources from which esters are produced. Probably petroleum-source synthetics will eventually be the most widely used type. Another

table lists properties of di-esters and synthetic oils.

THE THICKNESS OF OIL FILMS AT METAL SURFACES
by F. Schiessl, Kolloid Zietschrift, Vol. No. 2/3, Dec. 1952, pp. 84-91.
By means of an optical interference method, films have been prepared which reproduce the tear-off process between two metal plates in vertical direction, oil being the intermediate layer. The curves obtained by evaluation of said films show that the thickness of a lubricating film is a function of time. The curves derived on the basic of hydrodynamic considerations contain, along with the term dynamic viscosity, another variable: the initial distance, which can be affected by the chemical constitution of the lubricant, the mated materials and the state of the surface. The concepts which are here developed are especially important for boundary lubrication problems, where minimal distances occur, so that the lubricants may assume the properties of solid bodies.

WHAT'S HAPPENING IN LUBRICATING-OIL MANUFACTURE?
by E. P. King, Oil & Gas Journal, Vol. 51, No. 45, Mar. 16, 1953, pp. 122, 125-126, 128, 131, 134.
The boiling range and degree of stripping of distillate fractions, and the front-end distillation of residuum have a substantial influence on yields, throughputs, and operating conditions in processing lubricating oils. Distillation operations, optimum stripping required, propane deasphalting of residuum, contaminants of propane, temperature - gradient effects, raffinate considerations, MEK-toluene dewaxing, and recrystallization are taken up.

(Section News, from 149)

equipment, and effect of contaminants on performance of lubricants. (Submitted by P. M. Ruedrich, Sec'y-Treasurer.)

TWIN CITIES: March meeting—M. E. Merchant, Cincinnati Milling Machine Co., discussed Metal Cutting, Cutting Fluids & Radioactive Cutting Tools, with illustrated lantern slides, and narrated a film entitled Fundamental Aspects Of Metal Cutting & Cutting Fluid Action. H. A. Hatfield, West Disinfecting Co., presented a paper entitled Dermatitis In Industry.

April meeting—Dr. L. Heard, Standard Oil Co. Research Laboratory, Whiting, demonstrated and lectured on "Fire Magic," The Science Of Combustion, in which he punctuated what Chemical Week called his "droll explanation" of combustion with smoke rings, green flames, and minor explosions. C. K. Olson, Standard Oil Co., discussed Lubrication As It Is Effected By Combustion. (Submitted by W. H. Furst, Sec'y.)

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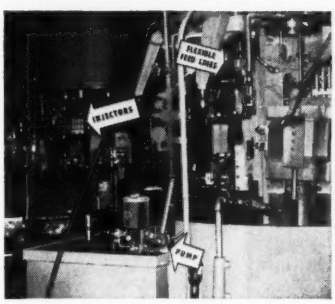

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WHEELING: (See Lubrication Summarized.)

YOUNGSTOWN: March meeting —B. J. Lamport, United Engineering & Foundry Co., presented a paper entitled Choosing Lubricants For Steel Plant Equipment (See Lubrication Summarized). (Submitted by R. S. Scheidemantel, Sec'y.)

(Lube in the News, from 152)

Luber system simultaneously applies controlled amounts of oil or light grease to the bearings while the press is in operation; optional flexible feed line and swivels are available for connection with motion-type bearings. Complete information, prices and technical data can be obtained by writing: Lincoln Engineering Co., 5743 Natural Bridge Ave., St. Louis 20, Mo., Bulletin 805.

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The Three Brothers

HOLDS A LESSON FOR CUTTING FLUID USERS

The Fable

THREE brothers inherited equal shares of their father's farm. One brother feverishly worked his land, with seldom a rest, until prematurely worn out, he died at an early age. The second brother loafed and played until his land went to ruin and he died for want of food. The third brother, wiser than the other two, *balanced* his work and play, so that he prospered mightily and lived to a ripe old age.

The Lesson

BALANCING the *chemical activity* of cutting fluids produces best results, too.

Figure 1 shows abnormal front clearance wear of a single point tool due to *excessive* chemical activity of the cutting fluid used. The tool failed prematurely, just like the first brother in the fable.

Figure 2 shows abnormal cratering of a tool due to *insufficient* chemical activity of the cutting fluid used. Such cratering is usually associated with poor surface finish. This tool failed prematurely like the indolent brother in the fable.

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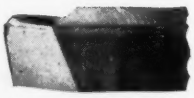

FIG. 1 — Abnormal front clearance wear caused by excessive chemical activity of cutting fluid.

FIG. 2 — Cratering of cutting tool, usually associated with poor finish, resulting from insufficient chemical activity of cutting fluid used.

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(Lubrication Summarized, from 151)

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@ 100 F., extreme pressure, prevents metal to metal contact which, in turn, prevents scoring, scuffing, welding and seizure with spalling.

The screw nut and spline of such a mill require special attention — here the recommended lubricant should be one that will feed readily to points of application and cling to the bearing surfaces when subjected to intense heat; it must be an extreme pressure product and have good metal wetting characteristics. A lubricant having viscosity of 510 SSU @ 210 F., to be pumped and measured by a motor operated grease system serving only the screw nuts and splines, is recommended, fluid enough to feed down along the spline and stiff enough to be retained on the threads of the screw nut.

(Patent Abstract, from 153)

sodium monocadmium salt of ethylene diamine tetraacetic acid and alkali metal fatty acid soap, the mount of said soap being from 1% to 20% the amount of said di-sodium mono-cadmium salt and the amount of said di-sodium mono-cadmium salt being sufficient with the water content of the solution to provide the desired density to the lubricant solution.

RUST INHIBITING COMPOSITION, Patent #2,631,979
by J. P. McDermott, assignor to Standard Oil Development Co.
A mineral lubricating oil containing dissolved therein 0.1% to 2% of a polymerized linoleic acid which consists essentially of the dimer.

PETROLEUM DISTILLATES CONTAINING AMMONIUM MAHOGANY SULFONATES & OIL SOLUBLE CARBOXYLIC ACIDS TO PREVENT CORROSION, Patent #2,632,694
by F. M. Watkins, assignor to Sinclair Refining Co.

Light petroleum distillate fractions into which have been incorported in synergistic proportions to impart anti-corrosive properties to the distillate fractions amounts in the range approximating 0.2 to 2.5 pounds of ammonium mahogany sulfonates on the oil-free basis and 0.05 to 5.0 pounds of a higher oil soluble carboxylic acid corrosion inhibitor selected from the group consisting of acyloxy-carboxylic acids having at least 10 carbon atoms per molecule, esterified alpha hydroxy aliphatic acids wherein the aliphatic radical contains from 10 to 18 carbon atoms per molecule and synthetic fatty acids having upwards of 18 carbon atoms per molecule and prepared by oxidation of C_{34} to C_{55} micro-crystalline waxes under controlled conditions, each per one thousand barrels of petroleum distillate.

RUST INHIBITOR FOR LIGHT PETROLEUM PRODUCTS, Patent #2,632,695 by P. S. Landis & E. B. Backensto, as-

signors to Socony-Vacuum Oil Co., Inc.

A normally liquid, non-lubricating mineral oil fraction containing a minor proportion, sufficient to prevent rusting of ferrous metal surfaces in contact therewith, of an antirust agent, selected from the group consisting of (1) dimeric acids produced by the condensation of unsaturated, aliphatic monocarboxylic acids having between about 16 and about 18 carbon atoms per molecule, (2) dimeric acids produced by the condensation of hydroxyaliphatic monocarboxylic acids having between about 16 and about 18 carbon atoms per molecule, (3) trimeric acids produced by the condensation of unsaturated, aliphatic monocarboxylic acids having between about 16 and about 18 carbon atoms per molecule, (4) trimeric acids produced by the condensation of hydroxyaliphatic monocarboxylic acids having between about 16 and about 18 carbon atoms per molecule.

STABILIZED HYDROCARBON FUEL OILS, Patent #2,632,696

by H. G. Smith, T. L. Cantrell & J. G. Peters, assignors to Gulf Oil Corp.

A fuel oil composition comprising a major amount of a hydrocarbon fuel oil and a minor amount, sufficient to stabilize the fuel oil against the formation of sludge, of (1) the reaction product prepared by reacting an aqueous slurry of 1 mol of a metal hydroxide selected from the group consisting of barium, strontium, magnesium and calcium hydroxides with from 2 to 4 mols of formaldehyde at a temperature not exceeding 200 F. and condensing the resulting product with from 0.5 to 1 mol of aniline and from 2 to 4 mols of a mono-alkyl phenol having from 4 to 12 carbon atoms in the alkyl substituent, and (2) the reaction product prepared by reacting, at a temperature not exceeding 200 F., 1 mol of ammonium hydroxide with from 1 to 5 mols of formaldehyde and from 1 to 4 mols of a mono-alkyl phenol having from 4 to 12 carbon atoms in the alkyl substituent, the weight ratio of product (1) to product (2) ranging from about 1:4 to 4:1.

EMULSIFIABLE METAL-WORKING LUBRICANT, Patent #2,632,734

by T. J. Nunn, J. W. Leach & A. G. Rogers, assignors to Standard Oil Development Co.

A composition consisting essentially of mineral base lubricating oil containing 5 to 40% by weight, based on the total composition, of lard oil, 3 to 25% of a combination of at least two different oil-in-water emulsifiers one of which is an alkali metal petroleum sulfonate of molecular weight within the range of 350 to 650 and the other is a long chain fatty acid ester of a polyhydric alcohol, and about 0.3 to 3% of calcium soap of fatty acids of the C_{10} to C_{24} range.

GREASE COMPOSITIONS, Patent #2,635,078

by F. H. Stross & S. T. Abrams, assignors to Shell Development Co.

A lubricating grease composition comprising 55-98% by weight of a mineral lubricating oil and 2-45% by weight of a colloidally dispersed metallic sulfide having a water solubility less than 0.0005 gram per 100 cc. of water at 20 C., said gel being one which has its normal water content replaced by said oil.

WATCH OIL, Patent #2,636,005

by J. S. Martin, Jr., assignor to Hamilton Watch Co.

A lubricant consisting of the ester of diethylene glycol mono ethyl ether and 9- and 10-meta-xylyl stearic acid.

GREASE COMPOSITIONS, Patent #2,626,899

by S. T. Abrams & F. H. Stross, assignors to Shell Development Co.

A grease composition comprising a major amount of lubricating oil, a cation exchange inorganic colloid dispersed therein, said colloid bearing at least 30% by weight thereof of hydrophobic cationic surface-active radicals, at least 50% of said radicals being in salt formation with an acid, said acid having an acid group containing an element having an atomic weight between 28.0 and 32.1.

METHOD OF MAKING HIGH VISCOSITY PRODUCTS HAVING PETROLEUM OIL BASE AND PRODUCT OF SUCH METHOD, Patent #2,627,938

by S. H. Frohmader & V. C. Archer, assignors to Research Products Corp.

The method of making a thixotropic composition containing petroleum oil and polyethylene having an average molecular weight of at least 3500, which comprises preparing a solution of said polyethylene in said petroleum oil at a temperature above the cloud point of said solution, said polyethylene comprising approximately 1% to 10% of the combined weight of said polyethylene and said petroleum oil, and cooling said solution uniformly and without agitation at a rate of at least about 45 C. per minute through a temperature range including the cloud point of said solution while maintaining the concentration of polyethylene in petroleum oil in said solution substantially unchanged.

MEDICINAL MINERAL OIL VEHICLE THICKENED WITH POLYETHYLENE, Patent #2,628,187

by S. H. Frohmader & M. J. Shoemaker, assignors to Research Products Corp.

A viscous composition having improved consistency and stability characteristics comprising a medicament and mineral oil containing dispersed therein polyethylene having a molecular weight of at least 3500 in an amount equal to approximately .25% to 50% of the combined weight of the polyethylene and the mineral oil, said polyethylene having been initially in solution in said mineral oil and said solution having been cooled at a rate of at least 30 C. per minute through a temperature range including the cloud point of said solution while maintaining the concentration of polyethylene in mineral oil in said solution substantially unchanged.

LUBRICATING GREASE, Patent #2,628,195

by J. R. Allison & W. L. Blalock, assignors to Leffingwell Chemical Co.

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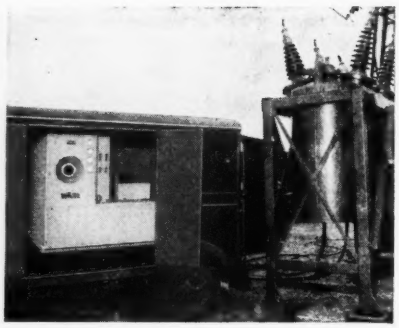

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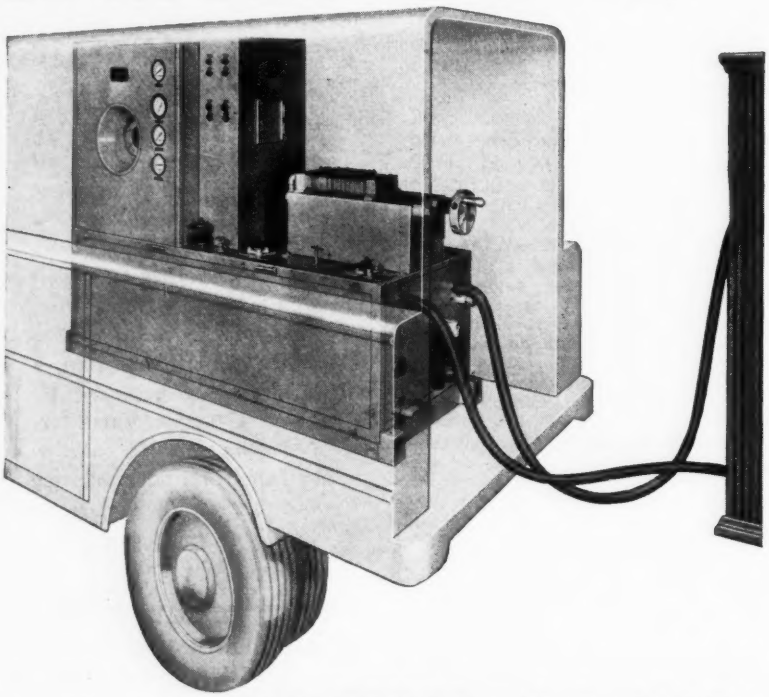

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soap of stearic acid and 2-ethyl hexanoic acid in situ in a lubricating grease formulation which consists in bringing said acids into joint solution in a mineral lubricating oil, mixing with said solution a small proportion of water and a base selected from the group consisting of the hydroxides and carbonates of aluminum, barium, calcium magnesium, strontium and zinc, and heating the mixture to a temperature above the boiling point of water to bring the resultant soaps into solution in said oil and to drive off any water contained therein; the proportions in which said acids are used being so controlled that the soap of 2-ethyl hexanoic acid represents from 1% to 35% of the weight of said compound soap.

METALWORKING LUBRICANT, Patent #2,628,197
by R. B. Killingsworth, assignor to Socony-Vacuum Oil Co., Inc.

An aqueous soluable cutting oil emulsion consisting essentially of mineral lubricating oil dispersed in water, an oil-in-water type emulsifier present in minor proportion sufficient to form a substantially stable oil-in-water emulsion and between about 0.1% and about 50% by weight of an organophilic bentonite characterized by a hydrocarbon chain of at least 10 carbon atoms.

ALKYL MALEATE-VINYL ACETATE COPOLYMERS, Patent #2,628,198
by E. Arundale & F. W. Banes, assignors to Standard Oil Development Co.

A lubricating composition consisting of mineral base lubricating oil of a viscosity of 35 to 800 SSU at 210 F. and 0.01 to 20% of a C_8 to C_{20} alkyl maleate vinyl acetate copolymer having an average molecular weight of 7000 to 25,000 and having a maximum molecular weight of not more than 40,000, said polymer being polymerized in the presence of an inert organic solvant and from about 0.1% to 5.0% by weight of a peroxide catalyst at a temperature of from about 30 to 60 C., said copolymerization being promoted by about 0.01 to 5% by weight of a ferric salt of a long chain fatty acid as an oxidizing agent and about 0.01 to 5.0% of an oil soluble organic reducing agent selected from the class consisting of benzoin, acetal, diacetone alcohol, diactyl acetone and acetonyl acetone as a reduction oxidation agent activator combination.

VISCOUS HYDROPHILIC COMPOSITION AND METHOD OF MAKING THE SAME, Patent #2,628,205
by M. J. Shoemaker, assignor to Research Products Corp.

A thixotropic hydrophilic composition comprising mineral oil, polyethylene and an emulsifier, said polyethylene having a molecular weight of at least 3500 and having been initially in solution in said mineral oil, said mineral oil-polyethylene solution having been cooled at a rate of at least 30 C. per minute through a temperature range including the cloud point of said solution while the concentration of polyethylene in mineral oil in said solution was maintained substantially unchanged.

PRODUCTION OF GREASES USING REACTION PRODUCTS OF ALPHA-HYDROXY FATTY ACIDS, Patent #2,628,938

by W. B. Whitney, assignor to Phillips Petroleum Co.

The production of a gel type lubricating grease which comprises effecting an esterification juncture of an hydroxy fatty acid with at least one of an hydroxy fatty acid and another fatty acid to produce a juncture product having a least sixteen carbon atoms to the molecule; converting the juncture product to a metal salt; and admixing said salt with a suitable lubricating oil to produce said grease.

STABILIZED LITHIUM BASE GREASE, Patent #2,628,949

by R. A. Butcosk, assignor to Socony-Vacuum Oil Co., Inc.

In a lithium base grease comprising a lubricating liquid comprising an ester of an organic acid and an alcohol selected from the group consisting of esters of aliphatic dibasic acids and of alcohols having from about four to about ten carbon atoms per molecule and esters.

POLYESTER SYNTHETIC LUBRICANTS, Patent #2,628,974

by R. T. Sanderson, assignor to The Texas Co.

A synthetic lubricant consisting essentially of a polyester formed by the reaction of an aliphatic dibasic acid containing 6 to 20 carbon atoms with a glycol of the group consisting of ethylene glycol, propylene glycol, butylene glycol, diethylene glycol and dipropylene glycol and a monofunctional compound containing 4 to 20 carbon atoms and selected from the group consisting of aliphatic monohydroxy alcohols and sliphatic monocarboxylic acids, the mol ratio of difunctional compounds in the reaction mixture being between 1.25 and 2.0.

(Book Reviews, Continued from 150)

1953 GUIDE TO APPROVED LUBRICATION FOR PASSENGER CARS & LIGHT TRUCKS

by Chek-Chart Corp., Publisher, 31 E. Congress Pkwy., Chicago 5, Ill., 1953, 144 pages, illustrations, price $18.00.

Unique "work-saver" lubrication charts, product of three years of development, appear in the 1953 LUBRICATION GUIDE. Keyed to the automotive service market, the edition includes charts for a greater percentage of the cars and light trucks actually in use, including all 1953 models; up-to-date redesigned charts cover passenger cars from 1953 back through 1941; in addition, charts covering 1940 through 1938 models of Chevrolet, Ford and Plymouth cars are included. Coverage of light truck models is similarly extended. A completely new Service Instruction section gives step-by-step

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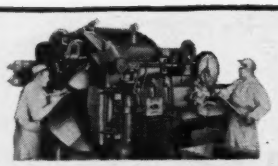

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procedures for servicing all points shown on all the individual charts. The edition is wire spiral bound across the top and the price includes a one-year subscription to the firm's publication, The Service Bulletin, in which regular departments keep Guide users up-to-date throughout the year on changes in lubrication recommendations and changes in service procedures.

(Johnson, Swikert, Bisson Cont'd from 149)

COMMENTARY by W. A. Zisman, Naval Research Laboratory: Information on the coefficient of friction at high sliding velocities has been needed for a long time, and the authors are to be congratulated for their vigorous program to satisfy this need. However, they have not always given correct interpretations of their data, nor have they always shown sound judgment in generalizing their results.

Early in their work the authors assumed that it was unnecessary to use adsorption methods to purify each oil before testing it. This was not sound as a large body of literature shows. The fact that they did not observe changes in friction after percolation may be attributed to either the existence of a hydrodynamic component of the friction in their test system because of the large sliding velocities used or possibly to the surface inactivity of the impurities present in the few test samples they checked. The results reported by Clinton at my laboratory in his study of the Four-Ball Wear Machine offer no justification for assuming that, because Clinton showed that at the lower loads the Four-Ball Machine did not operate entirely in the region of boundary friction. Even before being purified with adsorbant, the esters used by Clinton were relatively pure.

The authors indicate that the silicones have two limitations, one of which is indicated to be "inadequate oxidation resistance or thermal stability." I think it unwise to make such a broad statement without properly qualifying it in terms of their experimental facts or test conditions. The statement that "A private communication from a manufacturer of silicones indicates that the problem of increasing oxidation resistance and thermal stability is much less involved than that of improving lubrication" does not belong in a scientific paper. In effect, this is retailing gossip whose scientific correctness is debatable.

In referring to phosphonates the authors state "There has been speculation about probable toxicity and corrosiveness at elevated temperatures." Again I believe that this statement is too broad and is neither based on research of the authors nor on any information in the published literature.

Under "Experimental procedure", it is indicated that the lubricants tested were applied to the rotating disc as films which were believed to approach a monomolecular layer in thickness. The method used to obtain such thin films was to rub the excess off the wetted surface with lens tissue. A well known study by Germer and Storks is quoted to justify this assumption. The authors have made an erroneous interpretation, for the films described by Germer and Storks were formed by rubbing off the excess from a Langmuir-Blodgett multilayer of barium stearate. Such a material is oleophobic and all but a monolayer can be wiped off; however, that is a peculiarity of oleophobic compounds and not of the oils and other compounds tested by the authors. I doubt that the oiled surfaces tested were as thin as a monolayer.

The authors describe the lacquers formed at high sliding velocities and allege these are due to the chemical reaction of diesters with the steel to form soaps. More likely these lacquers are products of oxidation and/or cracking of the oil at the elevated temperatures developed at such high sliding velocities. It is improbable that the authors would have been able to see and identify the lacquers formed if the oil had been present in a monomolecular film. The type of reaction occurring is very important to the interpretation of these data, and the analysis given is much too casual.

I am critical of the statement "it is obvious from the experimental results reported herein that there is a considerable difference between the diesters and the petroleum oils in their ability to provide effective lubrication at high sliding velocities" and of the later conclusion that

"The polyalkylene glycol fluids provided effective boundary lubrication at sliding velocities substantially higher than those at which the petroleum oils were effective, but they were not effective at sliding velocities as high as were the diesters." These statements may be true for the particular grade or purity of the compounds tested; however, the authors are not correct when they imply that these are either fundamental or practical differences between the oils. There is no basis for a sound comparison of the performance possibilities of these classes of lubricants unless either they are all extremely pure when tested without antioxidants or unless they are all well inhibited against oxidation. It is well established that all types of either mineral or synthetic oils do not respond well to antioxidants. It is also established that some rather unstable materials can, with a suitably chosen antioxidant, achieve excellent oxidation stability; a well-known example is the response of the polyalkylene glycols to phenyl alpha naphthylamine. The failure of tripropylene glycol n-butyl ether to serve as a good lubricant in these tests should have been expected, since without a suitable antioxidant rapid breakdown will occur. Therefore, I believe the authors conclusion is too broad for their data when they say "This result would indicate that good lubricating ability is not common to all polyethers."

The early gradual drop in the coefficient of friction with an increase in sliding velocity is interesting, but there exists the important and obvious possibility that it is due wholly or in part to a hydrodynamic contribution to lubrication whose importance increases as the velocity of sliding increases. The authors are not justified in assuming boundary lubrication in experiments where the physical variables are altered so greatly. That the coefficient of friction is around 0.1 or less is no justification for concluding that boundary conditions of lubrication exist, since it is possible to obtain hydrodynamic lubrication with coefficients of friction much lower than 0.1.

The conclusion is made that the blends of silicone and diesters are better boundary lubricants

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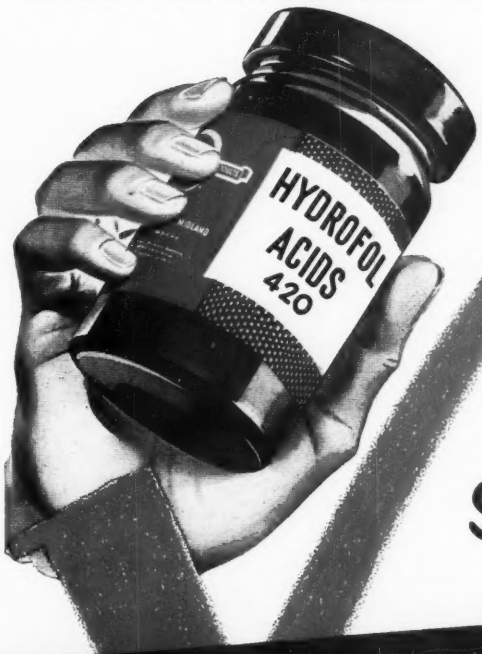

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than either constituent when taken alone. This needs qualification and reinterpretation. In work published by Merker and myself (Ind. and Eng. Chem. 41, 2546 (1949)) we showed that silicone-diester blends were valuable for the development of synthetic lubricants and especially for greases. However, a substantial proportion of diester was required for the frictional behavior to approach that of the diester alone. We found the boundary lubricating properties were never better than those of the diester alone. However, if the temperature was high enough, silicones polymerized to form lacquer which contributed to decreasing wear (see Brophy, Militz and Zisman, Trans ASME, May 1946).

In discussing the silicate esters it is remarked "Since one of the decomposition products of the silicate ester is silica, the sharp break in the friction curve might be a result of the formation of that harmful material as surface failure occurred." Unless the authors can cite good evidence that silica was formed, I believe their conclusion is not justified. More probably the observed sharp break in the friction-velocity curve is related to the boiling point of the silicate. Because there is so much commercial and governmental interest in silicates as synthetic lubricants for high temperature applications, it is a disservice to give such a casual treatment to the failure to lubricate observed in their apparatus.

With respect to the halocarbons, the unusual behavior of the fluids may be due to the relatively low boiling point which is characteristic of such halocarbons and not to E. P. effects as the authors suggest.

The authors remark "In the course of future development of the use of these fluids, it is important to have some basic understanding as to why esters lubricate" I think a good foundation already exists for our understanding of how esters lubricate and of the effect of carboxylic acid impurities developed through oxidation or hydrolysis. The main boundary lubrication problem in using esters as lubricants is to select or to develop those wear preventives which, while lowering boundary friction or decreasing wear, do not contribute to the decrease of the oxidation of hydrolytic stability of the ester. Too much research and development has been done during the past 12 years to justify the superficial treatment presented here.

The results obtained with a synthetic sapphire sliding on a Vycor glass disc are interesting, but there is no basis for concluding from their results that "chemical reaction may be important in lubrication by ester-type fluids." In going to nonmetallic bearing materials the authors have made such a great change in the ability of the system to dissipate heat that it is impossible to make a fair comparison of the behavior at high sliding velocities. The use of nonmetallic materials has probably caused more rapid heat generation and evaporation of the oil. The greater surface smoothness of these nonmetallic materials and the low tendency of esters to wet synthetic sapphires may also have contributed other variables to confuse the interpretation. The general proposition has been well established by Bowden and Tabor and by my own laboratory that good boundary lubrication is made more difficult to obtain with additives when unreactive bearing materials are used, and I think the authors have added confusion rather than clarity to the subject.

In conclusion, I think the authors have a valuable experimental apparatus which, if used as a physical-chemical tool rather than a test machine, can contribute valuable information in the near future.

AUTHORS' CLOSURE: The authors are indebted to Dr. Zisman for his very careful review of the paper and many of his points will be considered in our continuing research. While many of these comments are very good, some are open to dispute.

The basic consideration that purification by percolation methods would have no effect on friction results was based on considerable experimental information which, for the sake of brevity, was not presented in this paper. Friction data were obtained over an extremely wide range of sliding velocities with both purified and non-purified di

(2 ethyl hexyl) sebacate, and over a wide range of loads on six different friction machines including two from the Naval Research Laboratory (Annals N. Y. Acad. Sciences, vol. 53, art. 4, pp. 836-861), that indicate that friction data for both the percolated and non-percolated diester fall on a single line and that friction coefficient varies with sliding velocity. If friction values are Dr. Zisman's criterion of purity, it is of interest to note that the lowest sliding velocity data (0.0013 fpm) reported by the authors for non-percolated fluid resulted in a friction coefficient (0.20) which is higher than that reported by Dr Zisman's group as a static friction coefficient (0.18). These results cannot be explained on the basis that impurities serve to decrease friction; however, it is extremely difficult to obtain and maintain completely pure fluids by conventional laboratory techniques of purification and handling, particularly when friction runs are made in air.

In conducting research in the region of boundary lubrication at high sliding velocities, the authors are aware of the possible influence of a hydrodynamic component. Following the technique of Burwell and Strang (J. App. Phys., 1949, 20:79), plots at a number of sliding velocities of friction force versus normal load will show if a measurable hydrodynamic component is present. If a hydrodynamic component is present, a straight line drawn through the data points will not pass through the origin, but will show an intercept. Burwell and Strang state: "From the above argument, one may conclude that the fluid effects (hydrodynamic component) are responsible, at least in part, for the intercept of the friction force curves . . . .". Use of this technique for NACA data has failed to indicate any measurable hydrodynamic component over a range of sliding velocities with fluids in the viscosity range reported in this paper, provided the lubricant film is properly rubbed with lens tissue. We do not dispute the suggestion that such rubbing does not produce a mono-molecular film over the apparent area of contact. To attain such a condition with a rubbing technique would be impossible over the entire surface area because of surface topography alone. The film thickness is extremely thin on the surface asperities contacted by rubbing. The reviewer's comments on the physical-chemistry involved are most helpful in properly defining the surface condition, but certainly do not prove the existence of a hydrodynamic film.

Research at elevated temperature with many of these compounds will be reported in detail at a later date. Heating the phosphonate esters in air to their decomposition point produces noxious fumes and causes very marked discoloration of steel specimens at temperatures considerably below their decomposition points. Flammability studies of lubricants conducted by the University of Cincinnati under NACA contract showed that silica was a product of thermal decomposition of the silicate ester used in these studies.

The role of anti-oxidants in the failure characteristics of the various fluids has been considered by the authors. Some experimental data have been obtained with di (2 ethyl hexyl) sebacate using phenothiazine as the oxidation inhibitor. Concen-

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trations of that inhibitor up to 2 percent by weight had no influence on point of incipient surface failure (critical sliding velocity). Similarly, the use of 1 percent phenyl alpha naphthylamine in the silicate ester had no influence on the sliding velocity at which incipient surface failure occurred. As Bowden has shown, the localized surface temperatures in effective boundary lubrication may be above 600C. This is the condition of surface temperature that probably occurs when surface failure is obtained in the experiments reported herein, and such temperatures are generally considered to be far greater than the useful temperature limit for the oxidation inhibitors in current use.

The statement of results with the silicone-diester blend reported in this paper is, of course, limited to the conditions of these experiments. It is true, however, that, in runs with a high speed gear rig and a four ball apparatus at other laboratories, and with a modified SAE machine at the NACA laboratory, the blends produced better results than either the silicone or the diesters alone. Other data obtained with a Navy gear tester and a Falex tester, however, indicated that the diesters alone were better than the blend.

The suggested behavior of halocarbons is further supported by results obtained at the NACA laboratory with a SAE machine modified to operate in pure sliding. Under conditions which certainly led to vaporization of some of the fluid, there was no lubrication failure up to the load limit of the apparatus. It most certainly was not the intent of the authors to give the impression that silicate esters are not promising lubricants; to the contrary, they are considered to be one of the most promising types of fluids.

The rate of heat generation in sliding is a function of the friction force and sliding velocity, and is not a function of thermal conductivity of the specimens. The other factors mentioned could influence the results, although "the low tendency of esters to wet synthetic sapphire" may not be important since, from a lubrication standpoint, the more important of the two specimens in this case is the disk and the glass disk had a well formed lubricant film.

The reviewer has taken exception to speculation by the authors throughout the paper. Such speculation is designed to stimulate thought and discussion on the results so that they may be further clarified. These data (as well as all published data) are limited by certain qualifications, and no attempt should be made by the reader to "read into" the paper any broad and fundamental conclusions which are strictly outside the scope of the paper. It was indeed unfortunate that the necessity for brevity in the paper made it impossible to include much available data.

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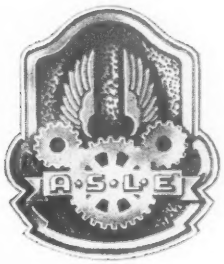

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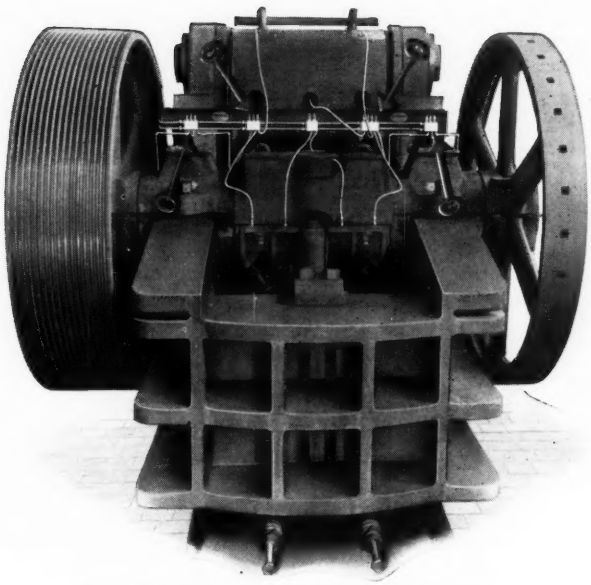

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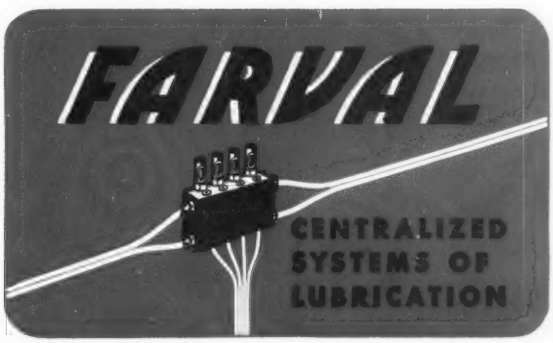

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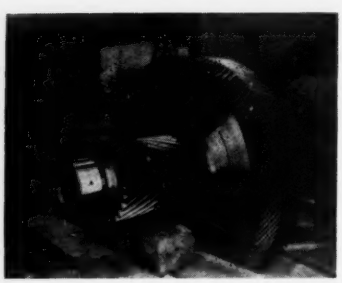

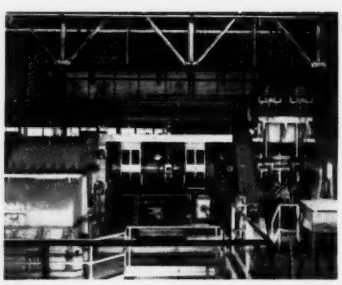

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